Innovative Operational Safety Improvements at Unsignalized Intersections

FINAL REPORT

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STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

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16. Abstract

This research is aimed at identifying innovative methods of improving safety at unsignalized intersection locations on high-speed, multi-lane roadways. Unsignalized intersections have a vast number of possible geometric and environmental configurations. No one treatment will be able to resolve all possible safety problems and in fact safety issues could potentially arise at intersections that meet all of the relevant design ‘standards’. Therefore, a broad range of innovative treatments are identified in this report to stimulate ideas for improving problem locations.

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EXECUTIVE SUMMARY

The intent of the *Innovative Operational and Safety Improvements at Unsignalized Intersections* research is to identify innovative methods of improving safety at unsignalized intersection locations, particularly on high-speed, multi-lane roadways. The information contained in this Final Report is intended to serve as a guideline, synthesizing the broad range of potential treatments that were identified through this project. Some of the treatments are more experimental, with just a few prior implementations nationwide, while others are more recognizable (but may not be widely used currently within Florida).

Unsignalized intersections have a vast number of possible geometric and environmental configurations. No one treatment will be able to resolve all possible safety problems and in fact safety issues could potentially arise at intersections that meet all of the relevant design ‘standards’. Therefore, a broad range of innovative treatments are identified in this report to stimulate ideas for improving problem locations where standard treatments have proven ineffective.

The overall project was divided into several tasks that included: (1) data collection and analysis of crash types and causes at urban and rural multi-lane roadway intersections, (2) a review of available literature, (3) a focused nationwide telephone survey of state departments of transportation and researchers, and (4) evaluation of possible countermeasures. This Final Report primarily focuses on Task 4. The results of the three initial tasks were presented in two stand-alone working papers that document those specific work activities. Information identified from the literature review and surveys was used in the countermeasure evaluation and the documentation of those countermeasures that is contained in this report.

Crash Analysis

Field data was collected at 23 unsignalized intersections in urban and rural environments, on four- and six-lane, divided and undivided, high-speed facilities. The 18 intersections in an urban environment displayed a wide range of crash types, however four types were predominate. These included: rear-end, left-turn, sideswipe, and angle crashes. In the rural locations, these crash types were also present; however, the most prevalent crash type tended to be single-vehicle run-off-the-road crashes resulting in rollover or hitting a fixed object. The contributory causes at these rural intersections is likely the combination of high operating speeds combined with inadequate warning devices to alert drivers to the presence of the intersection. Another potential crash cause noted in the literature review, but not directly observed in the crash analysis, was the inability of drivers on the minor road approaches to judge adequate gaps in traffic. The literature review identified that a large portion of angle crashes could be attributed to the inability to adequately judge gap sizes at intersections with a large cross-section.

At the 18 urban locations that were evaluated, access management and the design of auxiliary turn lanes was noted to have a particular effect on the observed crash patterns. Extended left- and right-turn lanes along the major roadway allow for vehicles to travel at high speeds down those lanes. When heavy queues are present in the through lanes of the major road, a minor street vehicle trying to “sneak” through the stopped vehicles may unexpectedly encounter a vehicle traveling at a high rate of speed in the auxiliary turn lane – resulting in a crash.

Using the FDOT Crash Analysis Reporting System, expected annual crash values were developed for a variety of crash type and environmental conditions. Separate crash values were identified for four scenarios: four-lane undivided, four-lane divided, six-lane undivided, and six-lane divided roadways. These expected crash values are intended to provide baseline values that can be used in identifying whether a particular crash type is abnormally high at a given location.

Literature Review and Surveys

The initial literature review conducted for this project provided a base level of information from which to select persons to participate in the telephone surveys and to develop the questions that were posed in the surveys. Based upon the outcome of the surveys, additional leads for literature and contacts were identified and incorporated into the project. Therefore, the survey and literature review was conducted as an iterative process to continually identify new information and follow new leads.

The outcome of the literature review and survey tasks was the identification of potential countermeasures. The countermeasures included unique variations on common treatments and truly innovative treatments that are being tested and considered nationwide.

Innovative Treatments

A wide range of common and innovative treatments were identified through the course of the project. Ultimately, 18 of those treatments were further investigated as part of this project. Within some treatments, such as vehicle actuated variable message signs, there may be an indefinite number of potential ways to configure the treatments. Treatments may also be configured in combination with one another and may need to be considered in combination with common intersection improvements. For each treatment, the identified literature was synthesized to provide a summary of applicable locations, potential safety benefits, maintenance considerations, compatibility with FDOT and other national design guidance, design considerations, and additional reference documents.

In most cases, the body of research for each individual treatment is limited and the available data may be useful to roughly indicate the potential benefits of a particular treatment, but are generally not sufficient to predict the effectiveness in potential applications. This Final Report provides guidance on the evaluation of a site and selection of countermeasures including: considerations for initial data collection and safety assessments, considerations for initial implementation of more 'common' treatments, and summarization of benefits and pertinent characteristics of innovative treatments to assist in countermeasure selection.

Some of the treatments identified through this project have been previously implemented in at least one location in Florida. However, the lessons learned from these test implementations often never make it beyond the district in which the test was conducted. It is the hope of the project team that this report will allow for statewide dissemination of more information related to innovative treatments and potentially spur new ideas.

The countermeasures identified in this report are not intended to represent a new standard or policy for the FDOT. Rather they are intended to supplement existing design policies and standards to assist engineers in identifying creative ways of improving safety problems where more traditional approaches have failed to be effective. As documented in the summaries of each individual countermeasure, some of the treatments may contain components not currently on the FDOT approved products list or may not be consistent with typical FDOT design standards. Therefore, this report should be treated as a reference guide that may be used in conjunction with local knowledge and professional judgment.

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This research is aimed at identifying innovative methods of improving safety at unsignalized intersection locations on high-speed, multi-lane roadways. Unsignalized intersections have a vast number of possible geometric and environmental configurations. No one treatment will be able to resolve all possible safety problems and in fact safety issues could potentially arise at intersections that meet all of the relevant design 'standards'. Therefore, a broad range of innovative treatments are identified in this report to stimulate ideas for improving problem locations.

CONTENTS SUMMARY

This report is divided into five key sections which provide information on crash causes, common and innovative treatments, countermeasure selection, and detailed information on each of the identified innovative countermeasures.

Unsignalized Intersection Safety and Crash Types

A summary of crash causes and crash types at unsignalized intersections are based upon the results of a review of crash data for two Florida corridors. Expected values of crashes are also provided based upon the roadway cross-section.

Common Treatments

'Common treatments', including standard signing, marking, or other safety improvements, are key to any safety improvement strategy. These should be used prior to, or in combination with any innovative strategy.

Innovative Treatments

Innovative treatments are those that are not commonly used in Florida, or are currently being experimented around the country. These treatments may be a solution at locations where normal geometric criteria have been met and where common treatments are not providing acceptable results.

Countermeasure Selection

Innovative countermeasures are summarized and categorized to aid in selecting potentially applicable treatments based upon the identified safety problem.

Countermeasure Summaries

Detailed descriptions of each countermeasure are provided to discuss applicability, potential safety benefits, design, and other pertinent information.

INTRODUCTION

Project Description

This research, sponsored by the Florida Department of Transportation (FDOT), is aimed at identifying innovative operational and safety improvements at unsignalized intersections. The emphasis of this project is on higher speed, multi-lane arterials with two-lane stop-controlled crossings.

The objective of this project is to investigate new strategies for Florida that have the potential to result in a reduction of crashes at unsignalized intersections with multi-lane roadways. Innovative countermeasures were explored and proposed that may have a positive effect on highway safety at unsignalized intersections in general, with an emphasis on higher speed, multilane arterials with two lane stop controlled crossings.

The number of fatalities either at an intersection or influenced by an intersection in the State of Florida had grown to 1,145 persons (1,054 crashes) in 2006 (Santos, FDOT State Safety Office). This is fifth consecutive year in which intersection related fatalities have grown in the state. When compared to the national statistics in the Fatal Accident Reporting System (FARS) database, the State of Florida has the dubious honor of being #1 in intersection related fatalities nationally.

FDOT, in the strategic highway safety plan, has set a goal to reduce the rate of fatalities and serious injuries occurring at intersections. One of the objectives for achieving this goal is "to improve intersection design and operation from minimum to optimal standards by addressing the following partial list of strategies…" Many of the identified strategies and others are addressed in this research project. Projects such as this are certainly a positive step toward the accomplishment of this goal.

Scope of the Report

The project team conducted three initial tasks. These included (1) an analysis of crash types and causes at urban and rural multi-lane arterial roadways, (2) a review of available literature, and (3) a focused nationwide survey of state departments of transportation and researchers. The results of these tasks were presented in two initial working papers.

The scope of this final report is to present details of the identified countermeasures including suggestions for selection and application of countermeasures in Florida.

An initial review of the available literature was conducted in late 2006, with a list of potential resources provided to FDOT in January 2007. This information provided a base level of information from which to select persons to participate in the telephone surveys and the questions that were posed in the surveys. Based upon the outcome of the surveys, additional leads for literature and contacts were identified and incorporated into the project. Therefore, the survey and literature review have been an iterative process to continually identify new information and follow new leads. A listing of sources is provided in Appendix B.

The outcome of the literature review and survey tasks was the identification of an initial list of countermeasures. The countermeasures included unique variations on common treatments and truly innovative treatments that are being tested and considered nationwide.

Some of the treatments identified through this project have been previously implemented in at least one location in Florida. However, the lessons learned from these test implementations often never make it beyond the district in which the test was conducted. It is the hope of the project team that this report will allow for statewide dissemination of information on innovative treatments, including case studies from individual district tests.

UNSIGNALIZED INTERSECTION SAFETY AND CRASH TYPES

Overview of Crash Analysis

To better understand the issues needing to be addressed at unsignalized intersections, a review of twenty-three unsignalized intersections within the State of Florida was conducted. Unsignalized intersections were chosen in urban environments as well as rural environments. The analysis also provides expected value analysis to be used to determine if a crash type is abnormally high at unsignalized intersections on four and six lane, divided and undivided, high-speed facilities.

It was shown in the eighteen urban unsignalized intersections analyzed and from the expected value analysis that the most frequent crash types are rear end, left turn and angle crashes. Contributory causes for these crash types are:

- *Rear end* – principally traffic congestion in the AM and PM peak periods and in urban environments.
- *Left turn* – high traffic demand resulting in queues from downstream signalized intersections blocking the median opening resulting in a pattern of left turn crashes.
- *Angle crashes* – high mainline volumes not generating enough gaps to safely accommodate the side street demand and not providing proper intersection sight distance.

For the rural unsignalized intersections, these crash types were also present but the most prevalent crash type was lane departure/overturned vehicle. The contributory causes are high speeds and the lack of warning devices to warn drivers of an intersection ahead. Some locations also experienced sight distance restrictions.

Although not captured as a crash pattern, in the crash analysis conducted for this project, a Minnesota DOT study (Harder, 2003) identified that one of the primary causes of crashes at rural unsignalized intersections is the inability to judge adequate gaps in traffic. The study identified that 56% of right-angle crashes were caused by an inability to judge adequate gaps. Only about 25% of the right-angle crashes were associated with a failure to stop on the minor roadway.

A study funded by the Iowa Department of Transportation (Maze, 2004) confirmed another finding of the Minnesota DOT study, that the crash rate increases and crashes become more severe with an increase in the minor street volume.

Summary of Crash Types

Crash summaries and collision diagrams were prepared for the study period, 2003 to 2005. In addition, hard copy police reports were reviewed to correct any miscoded crashes throughout the study period and to better understand the probable causes of the crash patterns at the study intersections. The crash analysis revealed a total of 916 crashes at the 23 study intersections. The predominant crash types were rear end (38.9%), left-turn (22.2%), sideswipe (10.3%) and angle (9.8%). Table 1 provides the overall frequency of crashes by crash type at the study intersections.

Table 1 Overall Crash Summary

Harmful Event	Total
Rear End	356
Head On	5
Angle	90
Left Turn	203
Right Turn	49
Sideswipe	94
Pedestrian	9
Bicycle	4
Fixed Object Above Ground	2
Sign (Post)	5
Guard Rail	3
Concrete Barrier Wall	3
Other Fixed Object	2
Ran into Ditch/Culvert	9
Overturned	10
Construction Barricade Sign	3
Utility/Light Pole	7
Other	62
Total	**916**

Field Review Notes

Each of the twenty-three unsignalized intersections analyzed for this study were reviewed in the field to see if contributing causes for the crash pattern could be observed. Particular attention was paid to the urban left turn and angle crashes and the rural lane departure crashes as these crash types typically have a higher crash severity than rear end crashes.

- *Left turn* – A review of the hard copy police reports shows that at six of the study intersections the left turn crashes mostly involved left turning vehicles and through vehicles in the outside lane. It was observed in the field, that these intersections have three through lanes and a continuous right turn lane. The left-turning vehicle is allowed to cross three lanes of congested traffic and then encounters a through vehicle traveling at a higher rate of speed in the continuous right-turn lane resulting in a vehicle to vehicle conflict. One option to address this condition is through access management techniques that prohibit left turn maneuvers across queues waiting at signalized intersections. Frequently, access to adjacent properties can be accomplished by means of a U-turn at another downstream median opening.
- *Angle* – The field reviews at five intersections with full median openings revealed that high volumes of traffic on the main line did not allow sufficient gaps to safely accommodate side street demand. In most cases, drivers would stack abreast in the median to wait for a second gap in the second direction of traffic. A second contributing cause to angle crashes was sight distance restrictions found at two intersections. As with the previously discussed left turn crashes, careful implementation of access management techniques as an option for improving this condition.
- *Rural Lane Departure* – In the rural environment, lane departure crashes with the vehicle overturned had the highest frequency. The field reviews revealed high speeds and the lack of warning devices to alert drivers of an intersection ahead. The evaluated intersections had low minor street volumes and drivers on the main line may not have expected traffic entering the road as there are no visual cues that may ‘advise’ drivers of a change in the roadway conditions.

Expected Annual Crash Values

As part of the crash analysis, expected value tables were developed using statewide data obtained from the FDOT Crash Analysis Reporting System (CARS). The objective of the expected value analysis was to establish a threshold value per crash type for unsignalized intersections on high speed facilities. The crash expected values can then be used to determine if a crash type is abnormally high at unsignalized intersections on high speed facilities. Crash expected values were developed for four-lane and six-lane divided and undivided roadways. Thirty intersections of each type were randomly selected to obtain the sample used in this effort.

The expected value tables show that the most frequent crash types are rear end, left turn, and angle crashes. These results are similar to the results found for the eighteen urban intersections previously discussed. The expected value tables for four and six lane divided and undivided facilities are provided in Table 2 through Table 5 in the following pages. It is relevant to highlight that the crash expected values for divided facilities are higher than for undivided facilities. These results are counterintuitive; one would expect a higher crash frequency on undivided facilities. However, these results may be explained by higher traffic volumes on divided facilities.

Table 2 Expected Annual Crash Values (4 Lane Undivided Unsignalized)

		Mean Crash per Year	Standard Deviation	Abnormally High Crash/Year 90th Percentile	Abnormally High Crash/Year 95th Percentile
COLLISION TYPE	Rear End	0.59	0.92	2.09	2.38
	Head On	0.08	0.21	0.43	0.49
	Angle	0.46	0.61	1.47	1.66
	Left Turn	0.31	0.56	1.23	1.41
	Right Turn	0.03	0.10	0.20	0.23
	Sideswipe	0.08	0.14	0.32	0.36
	Backed Into	0.02	0.09	0.16	0.19
	Coll. w/ Parked Car	0.00	0.00	0.00	0.00
	Coll. w/ Pedestrian	0.03	0.10	0.20	0.23
	Coll. w/ Bicycle	0.02	0.09	0.16	0.19
	Fixed Object	0.10	0.20	0.43	0.50
	Ran Off Road	0.01	0.06	0.11	0.13
	Overturned	0.03	0.10	0.20	0.23
	Other	0.26	0.54	1.16	1.33
	Total Crashes	2.05	2.41	6.02	6.78
SEVERITY	PDO Crashes	0.75	0.86	2.16	2.43
	Fatal Crashes	0.03	0.10	0.20	0.23
	Injury Crashes	2.26	3.52	8.05	9.16
LIGHT CONDITIONS	Daylite	1.46	1.87	4.53	5.12
	Dusk	0.05	0.12	0.24	0.27
	Dawn	0.03	0.10	0.20	0.23
	Dark	0.48	0.63	1.52	1.72
	Unknown	0.02	0.09	0.16	0.19
SURFACE CONDITIONS	Dry	1.75	2.14	5.27	5.95
	Wet	0.25	0.34	0.81	0.92
	Others	0.05	0.15	0.29	0.33
MONTH OF YEAR	January	0.19	0.33	0.73	0.84
	February	0.19	0.33	0.73	0.84
	March	0.21	0.31	0.72	0.82
	April	0.17	0.32	0.69	0.79
	May	0.14	0.28	0.59	0.68
	June	0.18	0.26	0.61	0.69
	July	0.03	0.10	0.20	0.23
	August	0.21	0.35	0.78	0.89
	September	0.22	0.40	0.88	1.00
	October	0.21	0.31	0.72	0.82
	November	0.15	0.28	0.61	0.69
	December	0.14	0.23	0.51	0.58
DAY OF WEEK	Monday	0.29	0.40	0.94	1.06
	Tuesday	0.40	0.70	1.56	1.78
	Wednesday	0.33	0.47	1.11	1.26
	Thursday	0.25	0.37	0.87	0.99
	Friday	0.36	0.47	1.13	1.28
	Saturday	0.24	0.34	0.81	0.91
	Sunday	0.17	0.28	0.63	0.71
HOUR OF DAY	00:00 - 06:00	0.13	0.23	0.50	0.57
	06:00 - 09:00	0.23	0.35	0.80	0.91
	09:00 - 11:00	0.28	0.48	1.07	1.22
	11:00 - 13:00	0.09	0.92	0.42	0.48
	13:00 - 15:00	0.36	0.47	1.13	1.28
	15:00 - 18:00	0.54	0.73	1.74	1.96
	18:00 - 24:00	0.43	0.49	1.56	1.78

Table 3 Expected Annual Crash Values (4 Lane Divided Unsignalized)

		Mean Crash per Year	Standard Deviation	Abnormally High Crash/Year 90th Percentile	Abnormally High Crash/Year 95th Percentile
COLLISION TYPE	Rear End	0.68	1.00	2.33	2.65
	Head On	0.02	0.08	0.16	0.19
	Angle	0.48	0.62	1.49	1.69
	Left Turn	0.19	0.37	0.79	0.91
	Right Turn	0.04	0.14	0.28	0.33
	Sideswipe	0.20	0.31	0.71	0.81
	Backed Into	0.03	0.13	0.25	0.30
	Coll. w/ Parked Car	0.01	0.06	0.11	0.13
	Coll. w/ Pedestrian	0.02	0.08	0.16	0.19
	Coll. w/ Bicycle	0.01	0.06	0.11	0.13
	Fixed Object	0.13	0.26	0.56	0.64
	Ran Off Road	0.06	0.13	0.26	0.30
	Overturned	0.03	0.10	0.20	0.23
	Other	0.21	0.41	0.88	1.01
	Total Crashes	2.12	2.56	6.33	7.14
SEVERITY	PDO Crashes	0.91	1.39	3.20	3.64
	Fatal Crashes	0.04	0.11	0.23	0.27
	Injury Crashes	1.97	2.35	5.83	6.57
LIGHT CONDITIONS	Daylite	1.50	1.70	4.29	4.83
	Dusk	0.07	0.16	0.33	0.38
	Dawn	0.03	0.10	0.20	0.23
	Dark	0.52	0.88	1.97	2.25
	Unknown	0.00	0.00	0.00	0.00
SURFACE CONDITIONS	Dry	1.79	2.16	5.35	6.03
	Wet	0.32	0.46	1.08	1.22
	Others	0.01	0.06	0.11	0.13
MONTH OF YEAR	January	0.25	0.43	0.95	1.09
	February	0.17	0.26	0.59	0.67
	March	0.24	0.30	0.74	0.84
	April	0.16	0.27	0.61	0.69
	May	0.12	0.24	0.52	0.59
	June	0.19	0.36	0.77	0.89
	July	0.21	0.32	0.74	0.84
	August	0.18	0.30	0.67	0.76
	September	0.13	0.31	0.64	0.74
	October	0.21	0.34	0.78	0.89
	November	0.17	0.31	0.68	0.78
	December	0.09	0.17	0.37	0.43
DAY OF WEEK	Monday	0.37	0.41	1.05	1.18
	Tuesday	0.34	0.44	1.07	1.21
	Wednesday	0.32	0.56	1.25	1.43
	Thursday	0.33	0.51	1.17	1.33
	Friday	0.37	0.62	1.39	1.58
	Saturday	0.26	0.38	0.88	1.00
	Sunday	0.13	0.28	0.60	0.69
HOUR OF DAY	00:00 - 06:00	0.18	0.42	0.86	1.00
	06:00 - 09:00	0.28	0.47	1.05	1.20
	09:00 - 11:00	0.13	0.23	0.50	0.57
	11:00 - 13:00	0.16	0.27	0.61	0.69
	13:00 - 15:00	0.28	0.38	0.90	1.03
	15:00 - 18:00	0.52	0.69	1.65	1.87
	18:00 - 24:00	0.58	0.86	1.99	2.26

Table 4 Expected Annual Crash Values (6 Lane Undivided Unsignalized)

		Mean Crash per Year	Standard Deviation	Abnormally High Crash/Year	
				90th Percentile	95th Percentile
COLLISION TYPE	Rear End	2.12	2.99	7.05	7.99
	Head On	0.12	2.13	0.47	0.54
	Angle	1.04	1.26	3.11	3.51
	Left Turn	0.57	0.77	1.84	2.08
	Right Turn	0.16	0.36	0.75	0.87
	Sideswipe	0.36	0.56	1.28	1.46
	Backed Into	0.07	0.13	0.29	0.33
	Coll. w/ Parked Car	0.00	0.00	0.00	0.00
	Coll. w/ Pedestrian	0.07	0.17	0.34	0.39
	Coll. w/ Bicycle	0.01	0.07	0.12	0.14
	Fixed Object	0.20	0.27	0.65	0.74
	Ran Off Road	0.04	0.11	0.22	0.25
	Overturned	0.05	0.12	0.26	0.29
	Other	0.41	0.48	1.21	1.36
	Total Crashes	5.23	6.10	15.26	17.18
SEVERITY	PDO Crashes	2.73	3.72	8.85	10.02
	Fatal Crashes	0.07	0.17	0.34	0.39
	Injury Crashes	4.01	4.10	10.76	12.05
LIGHT CONDITIONS	Daylite	3.69	4.38	10.90	12.28
	Dusk	0.08	0.17	0.37	0.42
	Dawn	0.12	0.21	0.47	0.54
	Dark	1.28	1.71	4.09	4.63
	Unknown	0.05	0.12	0.26	0.29
SURFACE CONDITIONS	Dry	4.28	4.82	12.20	13.72
	Wet	0.87	1.26	2.94	3.34
	Others	0.08	0.28	0.53	0.62
MONTH OF YEAR	January	0.35	0.45	1.08	1.22
	February	0.47	0.64	1.52	1.72
	March	0.52	0.70	1.67	1.90
	April	0.37	0.50	1.20	1.36
	May	0.41	0.63	1.45	1.65
	June	0.41	0.63	1.44	1.64
	July	0.35	0.47	1.11	1.26
	August	0.55	0.80	1.86	2.11
	September	0.40	0.64	1.45	1.65
	October	0.40	0.53	1.27	1.44
	November	0.47	0.62	1.48	1.67
	December	0.53	0.64	1.58	1.78
DAY OF WEEK	Monday	0.81	1.16	2.73	3.09
	Tuesday	0.83	1.11	2.64	2.99
	Wednesday	0.79	0.98	2.39	2.70
	Thursday	0.84	1.05	2.56	2.89
	Friday	0.93	1.22	2.94	3.33
	Saturday	0.59	0.79	1.89	2.13
	Sunday	0.44	0.58	1.39	1.57
HOUR OF DAY	00:00 - 06:00	0.35	0.50	1.18	1.33
	06:00 - 09:00	0.75	1.12	2.59	2.95
	09:00 - 11:00	0.64	0.89	2.11	2.39
	11:00 - 13:00	0.61	0.79	1.91	2.15
	13:00 - 15:00	0.76	1.06	2.51	2.84
	15:00 - 18:00	1.01	1.21	3.01	3.39
	18:00 - 24:00	1.11	1.51	3.58	4.06

Table 5 Expected Annual Crash Values (6 Lane Divided Unsignalized)

EXPECTED ANNUAL CRASH VALUE TABLE
6 Lane Divided UnSignalized

		Mean Crash per Year	Standard Deviation	Abnormally High Crash/Year 90th Percentile	Abnormally High Crash/Year 95th Percentile
COLLISION TYPE	Rear End	3.82	4.01	10.42	11.68
	Head On	0.18	0.41	0.85	0.98
	Angle	1.09	1.48	3.53	4.00
	Left Turn	0.58	1.15	2.47	2.83
	Right Turn	0.08	0.23	0.45	0.52
	Sideswipe	0.89	0.75	2.12	2.36
	Backed Into	0.04	0.11	0.23	0.27
	Coll. w/ Parked Car	0.01	0.06	0.11	0.13
	Coll. w/ Pedestrian	0.00	0.00	0.00	0.00
	Coll. w/ Bicycle	0.01	0.06	0.11	0.13
	Fixed Object	1.48	2.36	5.35	6.10
	Ran Off Road	0.09	2.13	0.44	0.50
	Overturned	0.03	0.10	0.20	0.23
	Other	1.00	1.10	2.81	3.16
	Total Crashes	9.30	7.82	22.17	24.63
SEVERITY	PDO Crashes	4.76	4.67	12.44	13.91
	Fatal Crashes	0.07	0.25	0.48	0.56
	Injury Crashes	7.87	7.00	19.39	21.59
LIGHT CONDITIONS	Daylite	6.08	5.10	14.47	16.08
	Dusk	0.20	0.32	0.73	0.83
	Dawn	0.15	0.29	0.63	0.72
	Dark	2.79	3.21	8.07	9.08
	Unknown	0.08	0.19	0.39	0.45
SURFACE CONDITIONS	Dry	7.18	6.06	17.15	19.05
	Wet	1.97	1.95	5.17	5.78
	Others	0.16	0.34	0.71	0.81
MONTH OF YEAR	January	0.69	0.62	1.72	1.91
	February	0.71	0.84	2.10	2.36
	March	0.98	0.99	2.61	2.92
	April	0.76	0.65	1.83	2.04
	May	0.77	0.82	2.11	2.37
	June	0.68	0.66	1.76	1.97
	July	0.84	0.89	2.30	2.58
	August	0.81	0.76	2.06	2.29
	September	0.91	1.10	2.72	3.06
	October	0.78	0.83	2.14	2.40
	November	0.74	0.80	2.06	2.31
	December	0.63	0.66	1.72	1.93
DAY OF WEEK	Monday	1.32	1.40	3.62	4.07
	Tuesday	1.22	1.12	3.06	3.42
	Wednesday	1.31	1.27	3.39	3.79
	Thursday	1.35	1.37	3.61	4.04
	Friday	1.51	1.36	3.74	4.17
	Saturday	1.23	1.25	3.30	3.69
	Sunday	1.34	1.64	4.03	4.55
HOUR OF DAY	00:00 - 06:00	1.10	1.48	3.54	4.01
	06:00 - 09:00	1.11	1.28	3.21	3.61
	09:00 - 11:00	0.73	0.97	2.33	2.63
	11:00 - 13:00	0.80	0.89	2.27	2.55
	13:00 - 15:00	1.00	1.06	2.75	3.09
	15:00 - 18:00	2.08	1.69	4.86	5.39
	18:00 - 24:00	2.48	2.39	6.42	7.17

COMMON TREATMENTS

There are many safety countermeasures that are commonly implemented today. Although not part of this study, it should be recognized that common treatments are a vital part of safety improvement strategies. These treatments include access management, provision of turn lanes, improving lighting, and providing adequate sight distance. They can also include such treatments as installing larger regulatory and warning signs, and improved maintenance of signing and markings.

Table 6 indicates the treatments that, for the purposes of this study, are considered to be common treatments versus innovative treatments. This list is based upon treatments identified in NCHRP Report 500, Volume 5 – A guide for addressing unsignalized intersection collisions.

Innovative treatments alone should not be considered a replacement for good design. Significant research has been conducted regarding many of the more common treatments, including sight-distance and the use of exclusive left- or right-turn lanes at unsignalized intersections.

A review of the intersection design should be conducted to identify any deviation from current design standards. Intersection lighting and the visibility of the intersection to motorists should be assessed and enhanced where appropriate. This includes the roadway markings, which should be in good repair. Enlarging the regulatory and warning signs, providing additional raised pavement markers, and adding non-actuated beacons are all common treatments that should be explored prior to considering more innovative treatments.

Table 6 – Common Treatments[1]

1. Implement driveway closures/relocations
2. Implement driveway turn restrictions
3. Provide left-turn lanes at intersections
4. Provide longer left-turn lanes at intersections
5. Provide right-turn lanes at intersections
6. Provide longer right-turn lanes at intersections
7. Provide right-turn acceleration lanes at intersections
8. Provide full-width paved shoulders in intersection areas
9. Restrict or eliminate turning maneuvers by providing signing, channelization, or closing median openings
10. Close or relocate 'high-risk' intersections
11. Convert four-legged intersections to two T-intersections
12. Convert offset T-intersections to four-legged intersections
13. Realign intersection approaches to reduce or eliminate intersection skew
14. Clear sight triangles on stop- or yield-controlled approaches to intersections
15. Clear sight triangles in the medians of divided highways near intersections
16. Change horizontal and/or vertical alignment of approaches to provide more sight distance
17. Eliminate parking that restricts sight distance
18. Retime adjacent signals to create gaps at stop-controlled intersections
19. Improve visibility of the intersection by providing lighting
20. Provide a stop bar (or provide a wider stop bar) on minor-road approaches
21. Install larger regulatory and warning signs at intersections
22. Provide supplementary stop signs mounted over the roadway
23. Provide improved maintenance of stop signs
24. Provide traffic calming on intersection approaches through a combination of geometrics and traffic control devices
25. Post appropriate speed limit on intersection approaches
26. Provide turn path markings

[1] Identified in NCHRP Report 500, Volume 5

INNOVATIVE TREATMENTS

For the purposes of this report, innovative treatments may be variations of common treatments, new technologies, or unique ideas implemented in other areas of the country or world. Table 7 provides a list of the innovative treatments investigated as part of the current research. For each treatment a brief description of the treatment and potential benefits is provided. Table 7 also provides a reference to the page of this report where the detailed treatment information is located.

The remainder of this document will be used to:

- Provide guidance on where it may be appropriate to implement innovative treatments,
- Aid in the selection of applicable countermeasures, and
- Provide summaries on each of the identified countermeasures

Detailed summaries of each countermeasure are provided to aide engineers in identifying whether a particular treatment may be applicable and the benefits that may be expected. Treatments are summarized based upon a number of characteristics including:

- Net expected benefits and long-term effectiveness
- Design considerations
- Driver expectation
- Traffic flows and operational characteristics
- FDOT design standards
- MUTCD and AASHTO guidelines

Current FDOT Design Guidance

The Florida Department of Transportation has a variety of materials currently available that describe the standards and practices for state facilities. These documents include the following:

- FDOT Greenbook
- FDOT Design Standards *(For Design, Construction, Maintenance and Utility Operations on the State Highway System)*
- Florida Intersection Design Guide
- Florida Traffic Engineering Manual

In the detailed summaries for each countermeasure (contained at the end of this document), the FDOT design guidance has been referenced with key information relating to the treatments shown in tables and figures. The design guidance referenced in this document is current as of the date this document was prepared. The actual FDOT documents should be cross-referenced when considering a treatment to ensure that current design guidance is being utilized.

Many of the innovative treatments described in this document are not currently discussed in the FDOT design documents. For these treatments, guidance from other states is provided. Designers should consult FDOT when considering treatments that lack FDOT guidance. Coordination with FDOT is crucial to ensure that the products being considered are approved for use on state roadways and that the design criteria are consistent with other state guidance.

Several treatments identified in this document as ‘innovative’ are already treatments that are utilized in the state. These include offset left-turn lanes and indirect left-turn treatments. These treatments are being included in this document to emphasize their use and expand upon the area types where these treatments are currently being applied. For example, indirect left-turn treatments and the associated access control strategies are commonly used in urban environments in Florida; however, they are just as applicable in the rural environments and may provide significant safety benefits even on high-speed rural roadways.

Table 7 Index of Innovative Treatments

	Treatment	Level Category (1, 2, or 3)	Treatment Detail – Page(s)	Brief Description	Potential Safety Benefits
Pavement Markings	Dotted Lines Through Full Median Openings	1	23-25	Extend the major street edge line through a median opening using a dotted line pavement marking	▪ Better define the median area for two stage gap acceptance ▪ Improve lane delineation for large median openings.
	Double-Yellow Markings within a Median Opening	1	27-28	Used for wide median openings to improve lane delineation	▪ Encourage two stage gap acceptance. ▪ Discourage multiple vehicles from stacking side-by-side within median opening
	Pavement Legends	1	29-33	Pavement legends could include arrows, symbols, or messages to improve guidance to motorists.	▪ Painting a warning sign on the pavement may help to emphasize intersection ahead or other warnings. ▪ Arrows and messages such as “Stop Ahead” provide supplemental guidance to drivers.
	Peripheral Transverse Pavement Markings	2	35-38	Pavement markings placed perpendicular to the flow of traffic to	▪ Used to emphasize signing and alert drivers of upcoming hazards ▪ May provide speed reductions
	LED Raised Pavement Markers	2	39-42	RPMs with embedded LED lights are used to enhance pavement markings and provide improved nighttime visibility	▪ Could be used to outline intersections to improve visibility ▪ Hardwired RPMs could be used in conjunction with detection to flash when a driver is approaching too fast or when a conflicting vehicle is present.
Signs and Beacons	LED Lights Embedded in Signs	2	43-45	LED lights are embedded into regulatory and warning signs to increase visibility	▪ Reduce instances of failure to stop and increase the conspicuity of approaching intersections to drivers.
	Post Mounted Flashing Beacons	2	47-49	Detectors used to identify the presence of vehicles and activate flashing warning beacons	▪ Can be use in a variety of configurations to emphasize a stop sign, promote two-stage gap acceptance, or warn major road drivers of conflicting traffic.
	Dynamic Speed Signs	2	51-53	Provides real-time speed information to drivers. Typically shown in conjunction with the speed limit sign.	▪ When combined with intersection-ahead warning signs, the dynamic speed signs may help to both draw attention to the warning sign while also reducing speeds through the intersection.
	Roadside Markers	2	55-56	Provide flexible markers or other objects along the roadside to assist drivers in judging vehicle speeds	▪ Assist drivers in identifying acceptable gaps in oncoming traffic.
	Vehicle Actuated Variable Message Signs	3	57-61	Vehicle detection provides real-time information to signs on both the major and minor roadways to warn drivers or conflicting vehicles	▪ Especially applicable to locations where sight distance is limited. ▪ Aids drivers in identifying conflicts and improves decision making in selecting gaps.

Table 7 Index of Innovative Treatments (Continued…)

Physical/Geometric Modifications	Transverse Rumble Strips	2	63-67	Rumble strips placed across the travel lanes. Can be either grooved in or raised.	▪ Provides audible and tactile warning of upcoming intersection to improve compliance with Stop signs. ▪ Could be used on the major roadway to emphasize the location of an upcoming intersection on high-speed facilities.
	Median Rumble Strips – Lane Narrowing	2	69-71	Lanes narrowed and median area delineated with rumble strips on minor approach. On the major roadway, lane markings could be used to create lane narrowing.	▪ Provide speed reductions through the intersection area. ▪ Avoid drivers making lane change maneuvers within the intersection area. ▪ Raise driver awareness of the intersection.
	Median Acceleration Lanes	3	73-77	An acceleration lane is provided within the median area to allow a two-stage left-turn onto the major roadway	▪ Allows drivers to complete a left-turn maneuver in steps and merge into traffic at more consistent speeds. ▪ Especially useful where large volumes of trucks are present.
	Indirect Left-Turn Treatments	2	79-84	Includes access management strategies for minor roadways and driveways. Could also be configured to prohibit left turns from major roadway and instead do a downstream U-turn	▪ Reduce the number of intersection conflicts ▪ Serious injury/fatality rates lower for U-turn movements than for a direct left-turn.
	Offset Left-Turn Treatments	2	85-88	Striping or geometric modification to offset the left-turn lane(s) from the adjacent through lanes in the same direction.	▪ Improve visibility for drivers making a left-turn. ▪ Allows drivers to see around an opposing vehicle to judge gaps in oncoming traffic.
	Roundabouts	3	89-94	Modern roundabouts can be used as an alternative intersection treatment to improve intersection operations.	▪ Promotes slow, consistent speed to reduce crashes, - especially serious injury and fatalities.
	Minor Approach Splitter Islands	2	95-98	Raised island separating the two directions of travel on the minor roadway approach to the intersection	▪ Provides positive channelization to drivers, warns of upcoming intersection, and improves visibility of the stop location. ▪ Helps to reduce instances of drivers running a stop sign.
	Alignment Modifications/Reverse Curvature	3	99-100	Geometric modifications made to the roadway alignment to slow drivers entering the intersection	▪ Large reverse curves result in a gradual reduction in speeds for drivers approaching the intersection. ▪ Slower speeds may result in lower crash severity and improve the ability of minor road drivers to adequately judge gaps in the conflicting traffic.

COUNTERMEASURE SELECTION

Guidance on countermeasure selection will be provided based upon crash type as well as the relative cost and impact (right-of-way, noise, etc.) of the treatment. Many of the innovative treatments are experimental and have been implemented at only a few locations. Therefore, caution should be used in the implementation of these treatments.

Countermeasure Selection Guidance

Decisions for the selection of a countermeasure should be based upon the field conditions and a review of the crash history. Crash patterns and root causes of a high crash location should be identified prior to selecting a countermeasure. The flow chart on Page 14 identifies several levels of data and assessments that should be taken into consideration in selecting a countermeasure. Countermeasure selection should consider both the physical features of the roadway as well as the context of the location.

Data Collection

Intersection characteristics should be reviewed and compared with standard design guidance. Additionally speed and volume data may be helpful in performing an operational analysis to determine if an operational deficiency is contributing to the overall safety problem. A minimum of three years of crash data should be obtained to be able to identify crash trends. Further, field data collection and observation should be considered a crucial part of this initial step in order to better understand the operating environment of the intersection.

Safety Assessment

A key step in establishing any safety improvement plan is to take the available data and discern the key safety problems and their root cause. In some cases, it may be a lack of driver compliance with the stop signs. At other locations, the speeds of approaching vehicles may make it difficult for minor road drivers to adequately judge gaps. Problems are likely to be different in an urban area versus a rural one, such as access management and issues based upon roadway cross-sectional characteristics. It is important to not approach the problem with a preconceived notion of what is required, but rather to investigate high-crash locations and have a clear understanding of the problem before beginning to identify a solution.

Intersection crash rates calculated for the study intersection can be compared against the expected values tables in this document (Tables 2 through 5) to assess whether intersection improvements are needed. In some instances, improvements may be justified regardless of the crash rate – including locations with a relatively low rate, but high percentage of severe crashes that are correctable.

In identifying the crash cause, consider the following sources of information for improving data reliability:

- Conduct field observations to assess the intersection operations under different traffic volume and lighting conditions.
- Contact the local law-enforcement officers for information regarding the study intersection.
- Interview local drivers stopped at the intersection to gain additional motorist perspective of the problem.
- Obtain the actual crash reports to verify the accuracy of the crash data.

Countermeasure Considerations

When evaluating potential countermeasures, a number of considerations should be taken into account including intersection control, target speeds, and location.

The application of more than one countermeasure may be appropriate in some locations to provide redundancy and/or address multiple crash types. The implementation of multiple treatments should consider the relative compatibility of those treatments. For instance, the use of rumble strips and vehicle actuated flashing beacons could be provided at a location experiencing low stop compliance. These treatments both work to increase intersection awareness and therefore could be considered compatible treatments.

Table 8 Flow Chart for Crash Analysis and Selection of Countermeasures

DATA CONSIDERATION			
Crash Records ▪ Type ▪ Severity ▪ Intersection Configuration ▪ Segment/Intersection Relationship ▪ Weather ▪ Time of Day	***Speed Data*** ▪ 85^{th} Percentile Speed ▪ Mean Speed ▪ Speed Variance ***Traffic*** ▪ Volume ▪ Composition ▪ User (Commuter, Recreation, Tourism)	***Intersection Features*** ▪ Type of Control ▪ Sight Distance ▪ Unconventional Features ▪ Lane Drops ▪ Merging ▪ Lighting ▪ Other Geometric Issues	***Environment*** ▪ Rural/Urban/Suburban ▪ Open or Closed cross-section ▪ Building offsets ▪ Landscaping ▪ Visual Complexity ▪ Pedestrians/Bicycles ▪ Driveway Density

SAFETY ASSESSMENT			
Types of Crashes ▪ What are the potential contributing causes for each of the predominant crash types? ▪ Are the crash types correctable?	***Crash Locations*** ▪ Where are crashes occurring? Segment, Transition, Intersection, Driveways? ▪ Environmental contributors ▪ Traffic volume and operational considerations	***Role of Speed*** ▪ Is speed itself an issue? ▪ Will speed reduction reduce crashes? ▪ Is the posted speed appropriate?	***Other*** ▪ Sight distance issues ▪ Access management issues ▪ On-street parking ▪ Signing & pavement marking

COUNTERMEASURE CONSIDERATIONS					
Approach Type ▪ Major or minor ▪ Stop-controlled ▪ Uncontrolled ▪ Yield Control	***Target Speed*** ▪ Design ▪ Posted ▪ Operating	***Location*** ▪ Segment ▪ Transition ▪ Intersection ▪ Urban ▪ Suburban ▪ Rural	***Type of Treatment*** ▪ Isolated ▪ Continuous ▪ Combination	***Potential Secondary Impacts*** ▪ Capacity ▪ Pedestrians/ Bicycles, ▪ ADA ▪ Land use ▪ Economics ▪ Enforcement Needs	***Design and Implementation*** ▪ Address public education and awareness ▪ Maintenance ▪ Long term effectiveness

SELECTING COUNTERMEASURES		
▪ Is a countermeasure appropriate? ▪ Are multiple crash causes present? o Are combinations of countermeasures needed? ▪ Are countermeasures needed on all approaches? ▪ What is the impact to adjacent properties	▪ Can countermeasures be used in conjunction with ITS or automated enforcement? ▪ Where should the countermeasures be applied? ▪ Relationship between segment and intersection.	▪ Distance required for speed transition (AASHTO Table) ▪ Cost ▪ Does applying the countermeasure impact the roadway capacity or traffic operations?

The AASHTO Strategic Highway Safety Plan (NCRHP Report 500, Volume 5) identifies a number of different strategies for improving safety at unsignalized intersections based upon the identified crash problems. These strategies from the AASHTO Strategic Highway Safety Plan are identified below. The accompanying discussion provides guidance on possible common and innovative treatments that would fall into each of these general improvement categories.

- *Improve management of access near unsignalized intersections* — Driveway access at or near an unsignalized intersection may confuse drivers using the intersection and create vehicle-vehicle conflicts. FDOT access management policies can be the basis for enforcing good management principles. At locations with existing median openings, the closure of a median (to provide a right-turn followed by a U-turn) has been documented to provide significant safety benefits (Lu, 2005).
- *Reduce the frequency and severity of intersection conflicts through geometric design improvements* — Reducing the frequency and severity of vehicle-vehicle conflicts at intersections can reduce the frequency and severity of intersection crashes. Common treatments may include providing separate left- or right-turn lanes or eliminating turning maneuvers from the intersection. Providing median acceleration lanes, introducing horizontal curvature, providing offset left-turn lanes, and median/U-turn improvements are some additional innovative treatments for improving safety.
- *Improve sight distance at unsignalized intersections* — Some collisions at unsignalized intersections occur because of limited sight distance for drivers approaching the intersection or for drivers stopped at an intersection approach. Where improving the sight distance is not feasible, innovative treatments are available such as Collision Countermeasure Systems which display real time information to motorists regarding the presence of conflicting vehicles.
- *Improve availability of gaps in traffic and assist drivers in judging gap sizes at unsignalized intersections* — Some collisions at unsignalized intersections occur because drivers have difficulty judging gap sizes before deciding whether to initiate a roadway entry or a turning maneuver. Drivers stopped to wait for the oncoming traffic stream often choose to proceed when oncoming vehicles are close, thus increasing the probability for a collision. Promoting two stage gap acceptance or providing supplemental information to drivers to aid in judging oncoming vehicle speed may help to improve intersection safety.
- *Improve driver awareness of intersections as viewed from the intersection approach* — Some intersection-related collisions occur because one or more drivers approaching an intersection are unaware of the intersection until it is too late to avoid a collision. Improved signing and delineation and installation of lighting can help warn drivers of the presence of the intersection. Numerous innovative treatments are available including the use of LED lights embedded in the raised pavement markers, stop signs, or warning signs. They also include the use of rumble strips, peripheral transverse pavement markings, splitter islands, pavement legends on the major roadway, and vehicle actuated flashing beacons.
- *Choose appropriate intersection traffic control to minimize crash frequency and severity* — The type of traffic control chosen for an intersection has a strong influence on the frequency and severity of crashes that occur at the intersection. The type of traffic control should be appropriate for the configuration of the intersection and the traffic volumes to be

served. An alternative to two-way or all-way stop control is the use of a multi-lane roundabout. Even on high-speed roadways, roundabouts have been shown to provide dramatic decreases in severe and fatal collisions due to the slower speeds for all vehicles traveling through the intersection.

- *Improve driver compliance with traffic control devices and traffic laws at intersections* — Many accidents are caused by noncompliance with traffic control devices or traffic laws at intersections. Enforcement has been shown to be an effective measure in reducing traffic-law violations and, consequently, in improving safety at intersections. However, other innovative treatments may also provide improved compliance. These include the use of vehicle actuated flashing beacons (or LED lights embedded in signs), real-time speed displays, and vehicle-actuated in-pavement lighting to alert drivers that are traveling at excess speeds.

- *Reduce operating speeds on specific intersection approaches* — At certain high-speed intersection approaches, implementing speed-reduction measures may provide an approaching driver with additional time to make safer and more efficient intersection-related decisions. The speed-reduction measure will get the driver's attention and prepare the driver for making a stop or other appropriate action, thus potentially reducing right-angle and rear-end collisions. Reducing speed is likely best accomplished through a combination of treatments. Geometric treatments such as a roundabout or reverse horizontal curvature will require all vehicles to slow down. Meanwhile other more passive treatments such as rumble-strips or peripheral transverse pavement markings may not provide the same level of speed reduction although they may still improve safety by increasing driver awareness of the upcoming intersection.

- *Guide motorists more effectively through complex intersections* — As drivers approach and traverse through complex intersections, drivers may be required to perform unusual or unexpected maneuvers. Providing more effective guidance through the intersection, through the use of signing and pavement markings, will reduce the likelihood of a vehicle leaving its appropriate lane and encroaching upon an adjacent lane. The additional guidance may also decrease indecision by drivers, thus reducing the potential for conflicts. Innovative markings, the use of lane line extensions through the intersection, and the use of pavement legends may help to improve motorist guidance in the vicinity of the intersection.

The selection of countermeasure treatments should begin with addressing the more basic treatments to provide an intersection that is fundamentally sound from a design standpoint. This includes determining that adequate sight distance is available, exclusive turn-lanes are provided, lighting is sufficient, etc.

Figure 1 identifies several generalized strategies for safety improvements at unsignalized intersections. Treatments are sorted based upon their relatively complexity from top (most common) to bottom (innovative). This list is not all inclusive, rather it is intended to illustrate the point that selection of treatment should start out basic and work towards the more innovative.

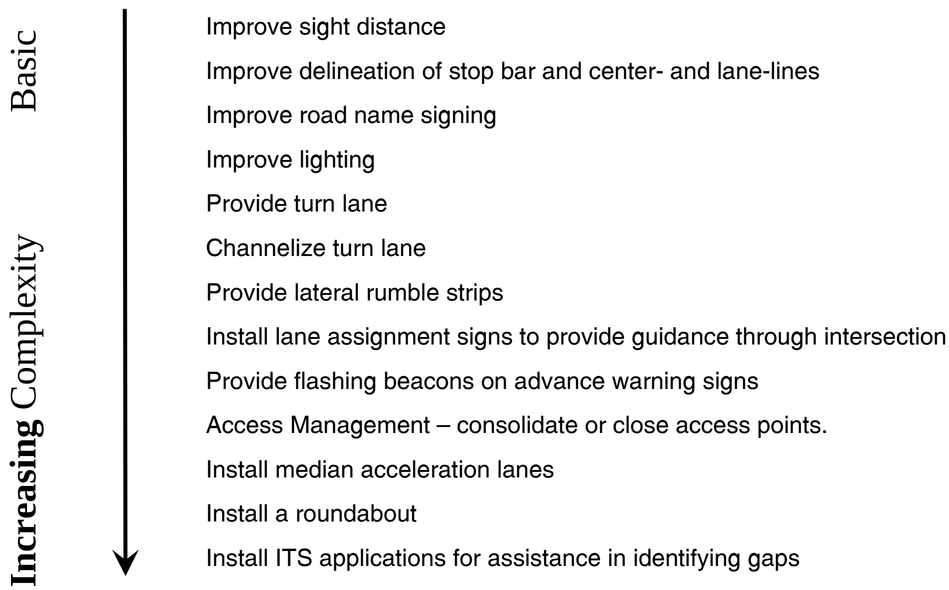


Figure 1 General Strategies for Safety Improvements at Unsignalized Intersections

Countermeasure Grouping and Summarization

Treatments with more widespread use or documented benefits may provide engineers with more predictable results than the uncertain experimental treatments. However, at problem intersections where other treatments have failed, the more experimental treatments may merit consideration. To assist in identifying the more common and easily implementable treatments versus the more complex ones, treatments were grouped into three levels. The general stratification is identified below:

- **Level 1:** Table 9 identifies treatments with known Crash Modification Factors (CMF's) or treatments that are extrapolations of common treatments. These may include flashing beacons on stop or warning sign posts, pavement marking improvements, etc. These treatments are likely to be the lowest cost and may be easily implemented without significant impact to physical roadway environment. Level 1 treatments are recommended for initial consideration, the same as more common treatments, as an initial improvement for intersection visibility or motorist guidance.
- **Level 2:** The second tier treatments, identified in Table 10, are those that are innovative treatments, but generally coincide with accepted practices from the MUTCD or other national guidance. The Level 2 treatments either have unknown insufficient data for reliable crash reduction determinations, or they are expected to result in a significant change to the physical roadway environment. Level 2 treatments include the use of detection to activate standard warning beacons, dynamic speed signs, rumble strips, and minor geometric improvements.
- **Level 3:** The final tier of treatments, identified in Table 11, are those that are the most experimental, have the highest cost, longest time to implement, or may have the largest impact to the physical environment. These treatments would include the ITS treatments (such as the Collision Countermeasure System) and roundabouts.

Tables 9, 10, and 11 also provide guidance regarding the crash types each innovative treatment is estimated to address. The crash types are the predominate ones previously discussed in the crash analysis.

Table 9 Level 1 Treatments

Countermeasure	Level of Known Data[1]	Level of Predictive Certainty[2]	Crash Types Addressed					Relative Cost	Time to Implement
			Angle	Rear-End	Left-Turn	Speed Related	Visibility		
Dotted Line Through Median Openings	4	Low	X		X			Low	Low
Post Mounted Flashing Beacon (Non-Actuated)	3	Low	X	X	X	X	X	Low	Low to Medium
Double-Yellow Centerline Within Median Opening	4	Low	X		X			Low	Low
Pavement Legends	3	Low	X	X	X	X	X	Low	Low

(1) 1 = Known AMF available
2 = Some data available, crash reductions known but not certain
3 = Some data available, crash reduction unknown/uncertain
4 = Little/No data available, countermeasure experimental

(2) Levels will include: High, Medium, Low, and Non-Existent. High indicates that the benefits are well known, whereas a Low indicates that the data results are inconsistent or the effectiveness of the treatment is not well known.

Table 10 Level 2 Treatments

Countermeasure	Level of Known Data[1]	Level of Predictive Certainty[2]	Crash Types Addressed					Relative Cost	Time to Implement
			Angle	Rear-End	Left-Turn	Speed Related	Visibility		
Peripheral Transverse Pavement Markings	3	Low		X		X	X	Low	Low
Transverse Rumble Strips	2	Low		X		X	X	Low to Medium	Low to Medium
Indirect Left-Turn Treatments	2	High			X			Medium to High	Medium to High
Offset Left-Turn Lanes	3	Medium			X			Medium to High	Medium to High
Median Rumble Strips	4	Non-Existent	X			X	X	Low	Low
Roadside Markers	4	Non-Existent	X		X			Low	Low to Medium
Dynamic Speed Signs	3	Low				X		Medium	Low to Medium
Minor Roadway Splitter Islands	3	Medium	X		X		X	Medium	Medium
LED Lights Embedded in Sign Face[3]	3	Low	X		X		X	Low	Low
LED Raised Pavement Markers[3]	4	Low				X	X	Low to Medium	Low to Medium
Vehicle Actuated Flashing Beacons	3	Low	X	X	X	X	X	Medium	Medium

(1) 1 = Known AMF available
2 = Some data available, crash reductions known but not certain
3 = Some data available, crash reduction unknown/uncertain
4 = Little/No data available, countermeasure experimental

(2) Levels will include: High, Medium, Low, and Non-Existent. High indicates that the benefits are well known, whereas a Low indicates that the data results are inconsistent or the effectiveness of the treatment is not well known.

(3) Not on FDOT Approved Products List (APL) at the time of this publication.

Table 11 Level 3 Treatments

Countermeasure	Level of Known Data[1]	Level of Predictive Certainty[2]	Crash Types Addressed					Relative Cost	Time to Implement
			Angle	Rear-End	Left-Turn	Speed Related	Visibility		
Roundabouts	1	High	X		X	X		High	High
Vehicle Actuated Variable Message Signs	3	Medium	X		X	X	X	High	High
Reverse Horizontal Curvature	4	Low				X		High	High
Median Acceleration Lanes	2	Medium	X	X	X			High	Medium

(1) 1 = Known AMF available
2 = Some data available, crash reductions known but not certain
3 = Some data available, crash reduction unknown/uncertain
4 = Little/No data available, countermeasure experimental

(2) Levels will include: High, Medium, Low, and Non-Existent. High indicates that the benefits are well known, whereas a Low indicates that the data results are inconsistent or the effectiveness of the treatment is not well known.

Countermeasure Summaries

Treatment: Dotted Lines Through Full Median Openings

Description

Placing dotted lines through full median openings is a treatment in which the left edge lines of the major roadway are extended as dashed markings across the full median opening at a divided highway intersection. The FDOT design standards do not currently provide these markings as a typical treatment. However, this treatment is currently implemented within Florida by some cities, counties and on some FDOT facilities.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 1
- **Quantity of Known Research Data:** little/no data available
- **Estimated Effectiveness of the Treatment:** Medium
- **Crash Types Addressed:** Angle, Left-turn
- **Cost:** Low
- **Time To Implement:** Low

Anecdotal benefits include:

- better defining the median area to enable drivers to judge median width for two-stage gap acceptance
- preventing vehicles from extending into the adjacent through travel lanes
- providing lane continuity

Applicability

"The target for this strategy should be unsignalized intersections on divided highways. The strategy is particularly appropriate for intersections with patterns of rear-end, right-angle, or turning collisions related to lack of driver awareness of the presence of the intersection" (NCHRP 500). This treatment will provide the benefit of better delineating the median opening area and is applicable to most median openings regardless of width or length. This treatment may be particularly useful for large or irregularly shaped median openings to provide lane continuity through the intersection. At narrow median openings, the treatment provides additional information to drivers to allow them to judge whether the width of the median opening is sufficient to provide refuge for two-stage gap acceptance.

Typical FDOT Median Opening – No Median Markings
Source: Microsoft Corp. (2008)

Dotted Lines through Median Opening (US 27)
Source: Google Earth (2008)

Figure 2 Example Median Opening Markings

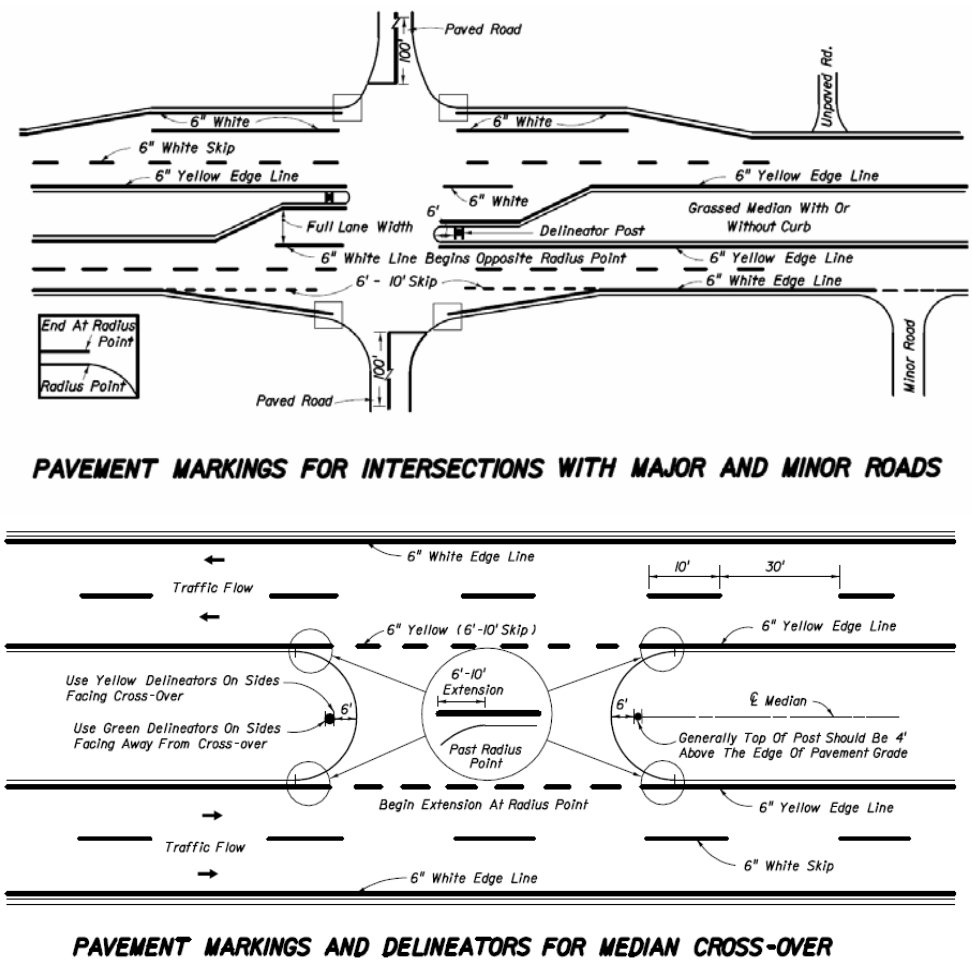
Treatment: Dotted Lines Through Full Median Openings (Continued…)

Potential Safety Benefits

- Reduce collisions between vehicles using the median roadway and through traffic (NCHRP 500).
- The extended edgelines "should make it less likely for drivers of vehicles in the median roadway to stop in a position with a portion of their vehicle encroaching on the through roadway"(NCHRP 500).
- Can help distinguish the median roadway from the through roadway (NCHRP 500).
- Increases awareness of approaching drivers to the presence of an intersection (NCHRP 500).

Compatibility with State and National Design Standards

The Florida Department of Transportation Design Standards provides guidance on the pavement markings at median opening locations. Standard Index Drawings 17346 shows the typical marking layout for the intersection of a major divided roadway, at a minor two-lane road (top drawing shown in Figure 3 below). Per Drawing 17346, the typical FDOT design omits any lane markings the median area. However, the FDOT design standards do utilize lane lines and dotted edge-line extensions through median cross-over areas (bottom drawing shown in Figure 3 below) and therefore provide some precedent for the design of the dotted edge-line extensions if they are utilized at full median openings.



Source: 2006 FDOT Design Standards, Index No. 17346, Sheet No. 1 of 13.

Figure 3 FDOT Standard Index Guidance for Median Opening Markings

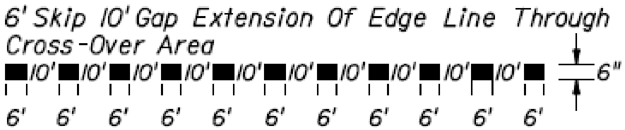
Treatment: Dotted Lines Through Full Median Openings (Continued…)

Maintenance

- Maintenance needs may be slightly higher than for typical lane line markings due to vehicles tracking over the top of the markings.

Design Considerations

- **Linetype -** An edge line extension marking through the median area should be a dotted linetype that provides noticeably shorter line segments separated by shorter gaps than used for a typical broken line.
    - To be consistent with FDOT practice at other locations, a dotted line with a 6-foot skip and 10-foot gap is recommended.



Source: 2006 FDOT Design Standards, Index No. 17346, Sheet No. 1 of 13.

- **Color –** If left-turn lanes are provided along the major roadway, the edge line extensions should be white to serve as an extension of the left-turn lane line. If there are not exclusive turn lanes from the major roadway, the line color will be yellow to serve as an extension of the left edge line (consistent with median cross-over areas).
- This strategy does not require a long development process and can typically be implemented in 3 months or less (NCHRP 500).
- Costs of implementing this treatment are relatively low (NCHRP 500).

Additional Reference Documents:

- Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, E. Kohlman Rabbani. NCHRP *Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C. (2003).

- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006).

Treatment: Double Yellow Markings within a Median Opening

Description

A solid double yellow centerline is placed, within a median opening to define the space for drivers to stop while making a two-stage crossing maneuver. When paired with wide stop bars on either side, it creates a small area where vehicles can stop and wait for an appropriate gap to cross or enter the highway from the minor street. This treatment is primarily applicable to locations with wide medians, where the goal is to promote drivers making a two-stage crossing maneuver from the side street.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Little/No data available
- **Estimated Effectiveness of the Treatment:** Unknown
- **Crash Types Addressed:** Side-swipe, Left-Turn, Angle
- **Cost:** Low
- **Time To Implement:** Low

Anecdotal benefits include:

- Defines the median area to prevent vehicles from encroaching on the through travel lanes.
- Reduces side by side queuing within the median to allow space for left-turning vehicles from the major roadway.
- Improves navigation guidance for motorists at wide median openings.

Applicability

- This treatment is applicable at unsignalized intersections on divided highways where side-by-side queuing and angle stopping within the median are common causes of accidents.
- At locations with wide medians where angle collisions are occurring on the far side of the intersection, drivers may not be adequately judging the speed of oncoming vehicles or the size of gap required to cross the wide roadway. In this case, providing stop bars and a double yellow within the median area may help to better define the space within the median opening to encourage two stage gap acceptances

Figure 4 Median Area Pavement Markings (Alachua County, FL)

Treatment: Solid Double Yellow-Line Within Median (Continued…)

- Providing stop bars at the edges of the median helps to define the median area and may prevent a driver from encroaching into the through travel lanes while waiting within the median area.

Potential Safety Benefits

- Helps prevent side-by-side queuing and stopping at an angle on the median roadway (NCHRP 500)
- "A double yellow centerline on the median roadway provides visual continuity with the centerline of the crossroad approaches and helps to define a desired path for drivers" (NCHRP 500).
- This treatment may make it easier for drivers on the major road to make U- or left-turns.

Potential Difficulties

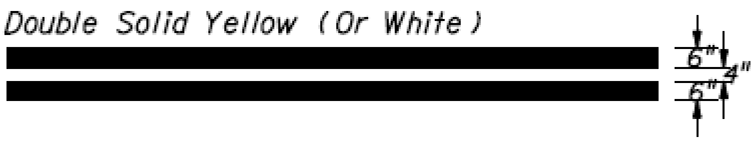
- It is possible that a narrow median roadway could cause vehicles to queue one behind the other and portions of vehicles could stick out into the through roadway (NCHRP 500).

Maintenance

- Ongoing maintenance is expected to be typical of lane line markings. To provide long-term durability, the use of thermoplastic markings may be appropriate.

Compatibility with State and National Design Standards

The Florida Department of Transportation Design Standards provides guidance on the design of solid double yellow-lines within the state.



Source: 2006 FDOT Design Standards, Index No. 17346, Sheet No. 1 of 13.

Design Considerations

- The median width is an important consideration. The double yellow-line within the median prevents vehicles from stacking in the median opening at an angle. Therefore the median should be able to store the design vehicle within the space provided without encroaching on the major roadway through lanes.
    - NCHRP Report 500 identifies a minimum width of at least 100 feet.
    - Other locations, including installations in Florida have been successful with smaller widths ranging from 50 to 80 feet.

Additional Reference Documents:

- Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, E. Kohlman Rabbani. NCHRP *Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C. (2003).
- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006).

Treatment: Pavement Legends

Description

Pavement legends are markings on the roadway surface within the travel lane. They include words, arrows, symbols, and other signs that can alert drivers of upcoming intersections, changes in roadway patterns, or information on route selection.

Applicability

Pavement legends can be used for warning, regulating, or guiding traffic. However, in Florida, they are currently typically used for the "STOP AHEAD" legend or lane use arrows. Some examples of other uses exist, such as the I-4 route shields in Orlando, which illustrate potential alternative uses of pavement marking legends to improve guidance to motorists.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 1
- **Quantity of Known Research Data:** Some data available, crash reductions unknown
- **Estimated Effectiveness of the Treatment:** Unknown
- **Crash Types Addressed:** Angle, Left-Turn, Speed, Visibility
- **Cost:** Low
- **Time To Implement:** Low

Anecdotal benefits include:

- Improving motorist awareness
- Simplifying navigation tasks
- Providing redundancy with warning signs where roadside "clutter" may limit sign effectiveness.

Texas has begun placing markings in the shape of warning signs, such as an Intersection Ahead sign. These are placed to complement existing warning signs along the roadside, with the intent of improving driver perception of the warning sign.

Potential Safety Benefits

- Improved driver awareness
- Provides supplemental means to communicate directions, warnings, and hazards effectively with the driver
- "Drivers who become drowsy can develop tunnel vision, where their ability to drive is reduced to the most basic driving task—following the path of the roadway. In this condition, even though a driver's peripheral vision and sign-reading skills may be restricted, he or she may still respond to messages painted on the pavement" (Morena, 2007).

Figure 5 I-4 Route Shields (Orlando, FL)

Maintenance

- Pavement legends are a transverse pavement marking that will be directly subjected to vehicles wear. To aid durability of the markings, thermoplastic is recommended.
- For legends with a large surface area, non-slick products such as TyreGrip (or similar) are recommended to improve traction over the legend. In an application by FDOT District 4, Tyregrip high friction surfacing systems was used at a location prone to run-off-road crashes and was found to be effective in assisting motorists in maintaining their lane position under wet conditions (FDOT Evaluation of Innovative Safety Treatments, 2008).
- Table 12, below, describes the expected service life and cost for pavement markings based on material used:

Table 12 Cost and Service Life of Marking Materials – 2001, Iowa State University

Marking Material	Expected Service Life (in years)[1]	Cost[2]
Traffic Paint	1/2 to 1	$0.10/ft
Epoxies	2 to 3	$0.60/ft
Poly Ureas and Urethanes	2 to 5	$0.85/ft
Thermoplastics	5 to 7[3]	$0.90/ft
Tapes	2 to 7[3]	$1–4.00/ft
Wet Reflective Tape	2 to 4	$1–2/ft

[1] Service Life can vary with traffic and weather conditions
[2] Cost based on averages, will vary based on quantities, locations, placement factors, etc.
[3] Night visibility may deteriorate earlier.
Source: Iowa State University, 2001.

Compatibility with State and National Design Standards

The 2000 *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance applicable to the design of pavement legends:

- In Section 3B.15, *Transverse Markings*, the manual states, "Transverse markings, which include shoulder markings, word and symbol markings, stop lines, yield lines, crosswalk lines, speed measurement markings, speed hump markings, parking space markings, and others, shall be white unless otherwise specified herein."

Figure 6 Pavement Legend (Texas DOT)

Treatment: Pavement Legends (Continued…)

- In Section 3A.04, *Colors*, the manual states, "Markings shall be yellow, white red, or blue. The colors for markings shall conform to the standard highway colors. Black in conjunction with one of the above colors shall be a usable color."
- In addition, "Because of the low approach angle at which pavement markings are viewed, transverse lines should be proportioned to provide visibility equal to that of longitudinal lines."
- In Section 3A.03, *Materials*, the manual states:

  Support:
    - Pavement and curb markings are commonly placed by using paints or thermoplastics; however, other suitable marking materials, including raised pavement markers and colored pavements, are also used.

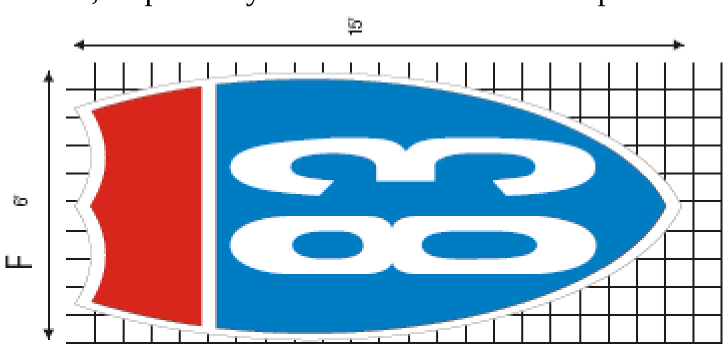
  Guidance:
    - The materials used for markings should provide the specified color throughout their useful life.
    - Consideration should be given to selecting pavement marking materials that will minimize tripping or loss of traction for pedestrians and bicyclists.
- In Section 3B.19, *Pavement Word and Symbol Markings*, the manual states:

  Support:
    - Symbol messages are preferable to word messages.

  Guidance:
    - Letters and numbers should be 6-feet or more in height.
    - Word and symbol markings should not exceed three lines of information.
    - The first word of the message should be nearest to the road user.
    - The number of different word and symbol markings used should be minimized to provide effective guidance and avoid misunderstanding.
    - Except for the "SCHOOL" word marking which extends the width of two approach lanes, all other pavement word and symbol markings should be no more than one lane in width.
    - Where through lanes become mandatory turn lanes, signs or markings should be repeated as necessary to prevent entrapment and to help the road user select the appropriate lane in advance of reaching a queue of waiting vehicles.

The *Manual on Uniform Traffic Control Devices* (MUTCD) *Standard Highway Signs* book provides guidance on the design of pavement legends within the United States:

- There are three accepted sizes of pavement signs: 6 feet, 7 feet, and 8 feet wide with lengths of 15 feet, 17.5 feet, and 20 feet, respectively. Shown below is an example of the smallest size:

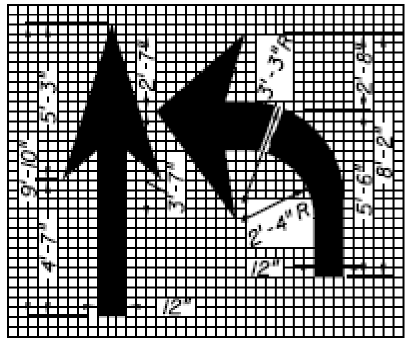


Source: MUTCD *Standard Highway Signs*, Page 10-23.

Treatment: Pavement Legends (Continued…)

The Florida Department of Transportation Design Standards provides guidance on the design and placement of pavement legends within the state:

- There are multiple shapes of pavement arrows. Shown below are two examples:

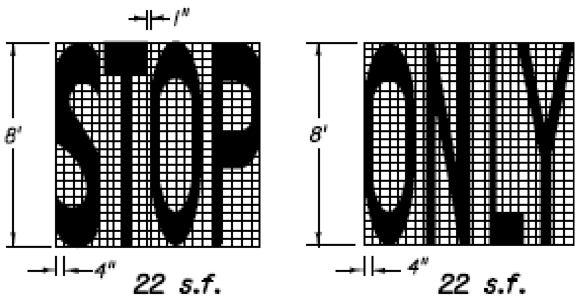


12 s.f. *16 s.f.*

Right Turn Arrow To Be Reversed

Source: 2006 FDOT Design Standards, Index No. 17346, Sheet No. 1 of 13.

- There are restrictions on letters and words. In certain cases such as school zones, railroad crossings, or bike lanes, the dimensions are different. Refer to the Design Standards for more details. Shown below are two examples of words:



Source: 2006 FDOT Design Standards, Index No. 17346, Sheet No. 1 of 13.

- Note: When arrow and pavement message are used together, the arrow shall be located down stream of the pavement message and shall be separated from the pavement message by a distance of 25 feet (Base of the arrow to the base of the message). Stop message shall be placed 25 feet from back of stop line.
- Refer to the Design Standards for details on placement and spacing of legends along the roadway.

Design Considerations

- Legends are typically viewed from a low approach angle and should be proportioned to provide visibility equal to that of longitudinal lines This may require the legend to have an exaggerated shape in the longitudinal direction to ensure legibility to drivers.
- It is not advisable to mix pavement arrows with pavement destination legends (Kinzel, 2003).
- Non-slip products, such as TyreGrip material, should be considered for pavement legends due with large surface areas. When roads are wet, legends could make the roads slippery, especially for motorcycles and bikes. Typical pedestrian crossing include a mixture consisting of 50% glass spheres and 50% sharp silica sand to all thermoplastic to improve the skid resistance of the roadway surface.

Additional Reference Documents:

- Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C. (2003).
- Federal Highway Administration. MUTCD Standard Highway Signs Book, 2004 Edition. http://mutcd.fhwa.dot.gov/ser-shs_millennium_eng.htm. Washington, D.C. (2004).
- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006).
- Iowa State University, Pavement Markings. *Iowa Traffic Control Devices and Pavement Markings: A Manual for Cities and Counties*. Iowa State University (2001). http://www.ctre.iastate.edu/PUBS/itcd (Accessed July 2007).
- Kinzel, Christopher S. *Signing and Pavement-Marking Strategies for Multi-lane Roundabouts: An Informal Investigation*. Urban Street Symposium (July 2003).
- Morena, David A.; Wainwright, W. Scott; Ranck, Fred. *Older Drivers at a Crossroads*. Public Roads. Federal Highway Administration, US Department of Transportation. January/February 2007, Vol. 70, No. 4. (July 2007). http://www.tfhrc.gov/pubrds/07jan/02.htm.
- Reddy, V., T. Datta, D. McAvoy, P. Savolainen, M. Abdel-Aty, Satya Pinapaka. *Evaluation of Innovative Safety Treatments*. Florida Department of Transportation, Tallahassee, FL (2008).

Treatment: Peripheral Transverse Pavement Markings

Description

Transverse pavement markings are placed perpendicular to the flow of traffic. There are many different examples of transverse pavement markings including shoulder markings, word and symbol markings, stop lines, crosswalk lines, speed measurement markings, parking space markings, and others (NCHRP Project 3-74). Peripheral transverse pavement markings refer to those markings that are placed along the shoulder and centerline of the roadway. These occur on the edges of the travel lane instead of bars extending fully across the travel lane (NCHRP Project 3-74).

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Some data available, crash reductions unknown
- **Estimated Effectiveness of the Treatment:** Low effectiveness on speed reduction. Crash reduction effectiveness unknown.
- **Crash Types Addressed:** Side-swipe, Intersection Visibility
- **Cost:** Low
- **Time To Implement:** Low

Anecdotal benefits include:

- Alert motorists to a change in roadway condition
- Minor speed reduction approaching an intersection.
- Encourage drivers to maintain the center of the lane, to prevent side-swipe crashes.

Applicability

Transverse markings may help to prevent crashes at high speed locations by alerting drivers of upcoming hazards, including intersection approaches and horizontal curves. The markings are easy to install and require a small amount of material, making them relatively cost effective. They are also located outside of the normal vehicle wheel path so they do not provide a slick surface under wet conditions. Markings could be provided either on the major or minor roadway. For multi-lane roadways, the markings would be placed at the edges of each travel lane.

Clackamas County, Oregon (Source: Unknown)

Source: Virginia Transportation Research Council

Figure 7 Example Applications of Peripheral Transverse Pavement Markings

Potential Safety Benefits

The goal of this treatment is to both alert drivers to the upcoming intersection and help to reduce speeds by visually narrowing the lane width.

- Initial field pilot studies conducted in the U.S. in Virginia, New York, Mississippi, and Texas indicate potential speed reductions of approximately 1 to 3 mph.
- Although the overall effect of this treatment on reducing vehicle speeds may be limited, there is insufficient data to determine the overall effectiveness of this treatment on improvement to safety. Anecdotally, the treatment may improve safety by alerting drivers to a change in roadway environment.
- Peripheral markings may help to keep drivers in the center of the lane and reduce the instances of drivers crossing the roadway centerline into the oncoming travel lanes on undivided roadways.
- A study on US Highway 60 in Meade County, Kentucky found crashes were reduced after transverse pavement markings were installed. During the prior six years, an average of eight crashes occurred at this location each year. During the year after installation three crashes were reported (Agent, 1980).
- An alternative marking pattern was tested by FDOT in 1999-2000 near Waldo, Florida (Griffin). Full transverse markings were used (stretching across the entire lane rather than just on the periphery of the lane) in a pattern that provided reduced spacing of the markings in the direction of travel of the motorist. This pattern was intended to make the motorist unconsciously feel as though they were traveling to fast. The results of this test indicated speed reductions of 3 to 4 mph in the 85th percentile sped. Five to six months after the installation, speeds were just 1 to 2 mph below the speeds prior to installation. These results are consistent with the studies cited for the peripheral transverse pavement markings. No discussion was provided in the project report on the impact of the treatment to crashes.

STUDY RESULTS ON SAFETY EFFECTS OF PERIPHERAL TRANSVERSE PAVEMENT MARKINGS

Study by: Virginia Transportation Research Council
Year: 2007
Results: (For two-lane roadways)

- At key locations of the study, relatively small, yet statistically significant, decreases in vehicle speeds ranged from 1.0 to 2.3 mph (p. 25).
- At one other location at the beginning of the bars, statistically significant decreases in vehicle speeds ranged from 4.8 to 5.9 mph with an average of 5.4 mph, a 12.3% decrease (p. 25).
- The theory of using the markings was that drivers would slow down as they tracked through the bars; however, this trend was not observed (p. 25).
- A costs and benefits assessment indicates (with one exception) that even if only one crash is prevented by the countermeasure, then the resulting savings exceeds the cost of implementation (p. 29).

Reference: *Evaluation of Best Practices in Traffic Operations and Safety: Phase 1: Flashing LED Stop Signs and Optical Speed Bars*

Study by: NCHRP, Project 3-74
Year: 2007
Results: After a 90-day acclimation period, transverse pavement markings were found to reduce speed marginally at the four sites at which tests were conducted. Overall, the markings reduced mean speeds by 0.6 mph.
Reference: NCHRP Web-Only Document 124, *Contractors Final Report for NCHRP Project 3-74.*

Maintenance

- Requires less maintenance than full transverse stripes due to the fact that the stripes are mostly outside of the wheel path of passenger vehicles.

Compatibility with State and National Design Standards

The Florida Department of Transportation Design Standards does not provide any guidance on the design and placement of peripheral transverse pavement markings within the state.

The *Manual on Uniform Traffic Control Devices* (MUTCD) provides some guidance that can be applied to the design of peripheral transverse pavement markings.

- In Section 3B.15, *Transverse Markings,* the manual states, "Transverse markings, which include shoulder markings…shall be white unless otherwise specified herein."
- In addition, "Because of the low approach angle at which pavement markings are viewed, transverse lines should be proportioned to provide visibility equal to that of longitudinal lines."

Design Considerations

Size and Shape of Markings

- Peripheral markings are usually one to two feet in length extending from both the edge line and centerline into the travel lane.
    - For a standard 12 foot lane, bars 18 inches in length may be appropriate to visually narrow the lane to 9 feet and still provide a 0.5 foot cushion to prevent a standard size (8.5 foot wide) truck from routinely tracking over the markings (Katz, 2007).
- Larger widths, up to 12 inches, is appropriate to improve the visibility of the markings to drivers. Markings should be larger than 4 inches, which were found to have lower visibility to drivers based upon field testing (Katz, 2007). A larger width for transverse markings is consistent with MUTCD policy.

Placement

- The distance before an intersection that the markings should be placed depends on the geometry of the site, the speeds of the approaching roadway, and the placement of other traffic devices along the segment.
- Markings should be placed in a location that provides adequate advance warning time for drivers to reduce their speed appropriately. The AASHTO Green Book values for deceleration may provide a starting point in locating transverse pavement markings (NCHRP Project 3-74).
- Generally, the transverse markings are placed at the same locations as warning signs to provide a redundant message to drivers that an intersection or other hazard lies ahead.

Marking Patterns

- Several different patterns (with respect to the spacing of the markings longitudinally along the roadway) have been field tested. These include both constant spacing and spacing that is reduced at an exponential rate. Markings with decreasing spacing are designed based upon the initial upstream speed and desired final speed to determine the number of bars and spacing between successive bars.
- The following diagram illustrates different marking patterns including (1) constant spacing, (2) exponential spacing, (3) 4 bars per second, and (4) 2 bars per second. The last two spacing schemes

have gradually reduced spacing based upon a comfortable deceleration rate from the initial speed to the final desired speed. Insufficient data is currently available to identify a preferred pattern. Based upon tests in Virginia, the 4 bar per second design was found to have greater speed reductions than the 2 bar per second design.

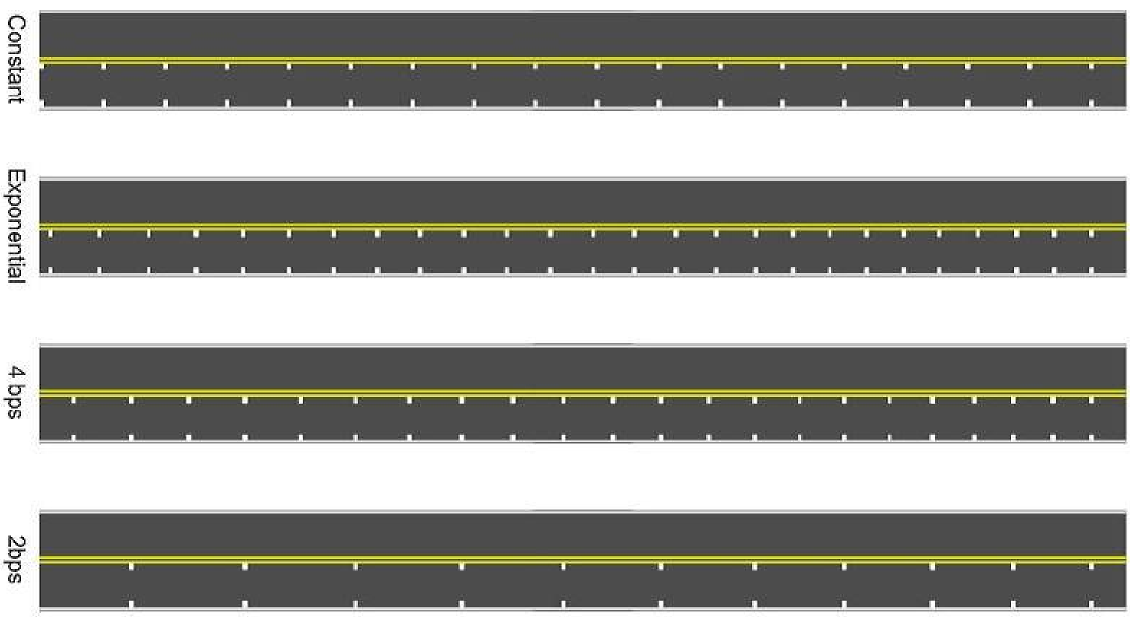


Figure 8 Examples of Peripheral Transverse Pavement Marking Patterns (Katz, 2007)

Additional Reference Documents:

- Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C. (2003).
- Katz, Duke, Rakha. *Design and Evaluation of Peripheral Transverse Bars to Reduce Vehicle Speeds*. (2005).
- Katz, Brian J. *Peripheral Transverse Pavement Markings for Speed Control*. Ph.D. dissertation, Virginia Polytechnic Institute (2007).
- Arnold, Jr., E.D. and Lantz, Jr., K.E. *Evaluation of Best Practices in Traffic Operations and Safety: Phase 1: Flashing LED Stop Signs and Optical Speed Bars*. Virginia Transportation Research Council. Charlottesville, Virginia (2007).
- Ray, B., W. Kittelson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, J. McGill, and D. Stewart. *Guidelines for Selection of Speed Reduction Treatments at High Speed Intersections*. NCHRP Web-Only Document 124, Contractors Final Report for NCHRP Project 3-74. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2007).
- Agent, K.R. *Transverse Pavement Markings for Speed Control and Accident Reduction.* Transportation Research Record: 773. TRB, National Research Council: Washington, D.C. (1980) pp. 11-14.
- Griffin, Lindsay, I. Evaluation of an Illusory Pavement Marking Pattern near Waldo, Florida. (2000).

Treatment: LED Raised Pavement Markers

Description

LED lights inserted into raised pavement markers (RPMs) can provide improved visibility of the roadway pavement markings. Over time, standard RPMs can become covered with dirt which reduces their retro-reflective qualities and their effectiveness. The use of LED lights may help to extend the effective life of the RPM's in addition to providing improved delineation.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Little data available, crash reduction benefits unknown.
- **Estimated Effectiveness of the Treatment:** High, Known reductions to overall crashes and serious injury crashes
- **Crash Types Addressed:** Speed related, intersection visibility
- **Cost:** Low to Medium
- **Time To Implement:** Low to Medium

Anecdotal Benefits include:

- Increase intersection visibility, particularly under low light conditions.
- Aid drivers in navigating the intersection
- Could possibly be paired with vehicle detectors to flash when conflicting vehicles are present or when approaching vehicles are traveling at excessive speeds.

SolarMarkers, Co

Figure 9 Example Application of LED Raised Pavement Markers.

LED RPM's are manufactured with a built in solar photocell that recharges the unit to allow for use independent of a hardwired power source. The LED RPM's also have built in sensors that automatically turn on the LED's when ambient light levels reach a preset level. Standard hardwired installations are also available that would allow for the RPMs to be manually controlled and could potentially be used as an active treatment in conjunction with vehicle detection.

Applicability

- LED RPMs could potentially be implemented anywhere RPMs are currently provided, including lane line delineation, gore areas, or painted channelization.
- Placing LED RPMs at specific locations, such as intersections or large horizontal curves, may help to emphasize those locations and raise driver awareness.
- Texas DOT has implemented LED RPMs on the roadway edgeline and centerline. These are typically employed in the vicinity of the intersection in conjunction with other treatments such as rumble strips, flashing beacons on the sign posts, etc. LED RPMs are currently used only at night and operate in a solid mode.
    - They have not tried flashing operation of the lights at intersections, however they do use flashing LED RPMs in advance of horizontal curves. At the curve locations, radar is used to detect vehicle speeds and activate the flashing RPMs when speeds exceed safe levels for negotiating the curve.

Potential Safety Benefits

- Increase the visibility of intersections for night-time and low visibility conditions.
    - Illumination of each of the legs of the intersection may help to make the identification of the minor roadway easier for nighttime driving, thereby reducing single vehicle crashes.
    - Where a vertical or horizontal curve limits sight distance to an intersection, the LED RPMs may help to provide advance notification to drivers of a possible conflict.
- If paired with a vehicle detector (such as loops, video, or radar), the LED lights could be set to flash when vehicles are approaching at an excessive rate of speed or when a conflicting vehicle is present at the intersection.

Potential Difficulties

- Hard wired LED RPMs have been found to be brighter than the solar powered models.
- In-pavement lights may be preferred to Raised Pavement Markers from a maintenance standpoint if hardwired RPMs are used rather than solar powered units. However, in-pavement lights are currently reserved for pedestrian crossings in the current 2000 version of the MUTCD.

Design Considerations

- Based upon survey feedback, the RPMs used in Texas are a metal case that have thus far shown a good ability to withstand traffic demands. RPMs have been installed for approximately one-year and no additional work has been required to date.
- Additional cost compared to standard RPMs. Survey feedback from Texas DOT indicated material and installation costs were approximately $50 per photocell unit.
- **MUTCD Guidance -** LED lights are currently allowed within raised pavement markers to accentuate the pavement markings. The 2003 MUTCD, section 3B.11 – 3B.14 provides guidance on the use of raised pavement markers including color and spacing. In general, the RPMs should be used to supplement the longitudinal markings and should be of the same color as the pavement marking that is being accentuated.
- **FDOT Guidance –** Guidance on the use of RPMs within Florida is provided within both the standard index drawings and the state specifications office. Only Class B RPMs may be used.
    - Standard Specifications Section 706 provides instruction on application of RPMs to the roadway.

- o Standard Index Drawing 17352 provides guidance on the placement of raised pavement markers on State roadways. At intersections, this includes the areas of channelization and along lane lines approaching the intersection.
- o Standard Index Drawing 17345 provides guidance on the placement of raised pavement markers at interchanges and ramps. RPM's could be used in a similar fashion as ramps with bi-directional white/red RPMS lining the white edgeline in the vicinity of the intersection to provide additional emphasis.
- o RPM Color varies by location as illustrated below:
  - ▪ Bi-directional White/Red RPMs should be used within gore areas separating traffic in the same direction or for delineating lane lines.
  - ▪ Bi-directional Yellow RPMs should be used in conjunction with double yellow lines – both roadway center lines and areas of channelization using double yellow lines.

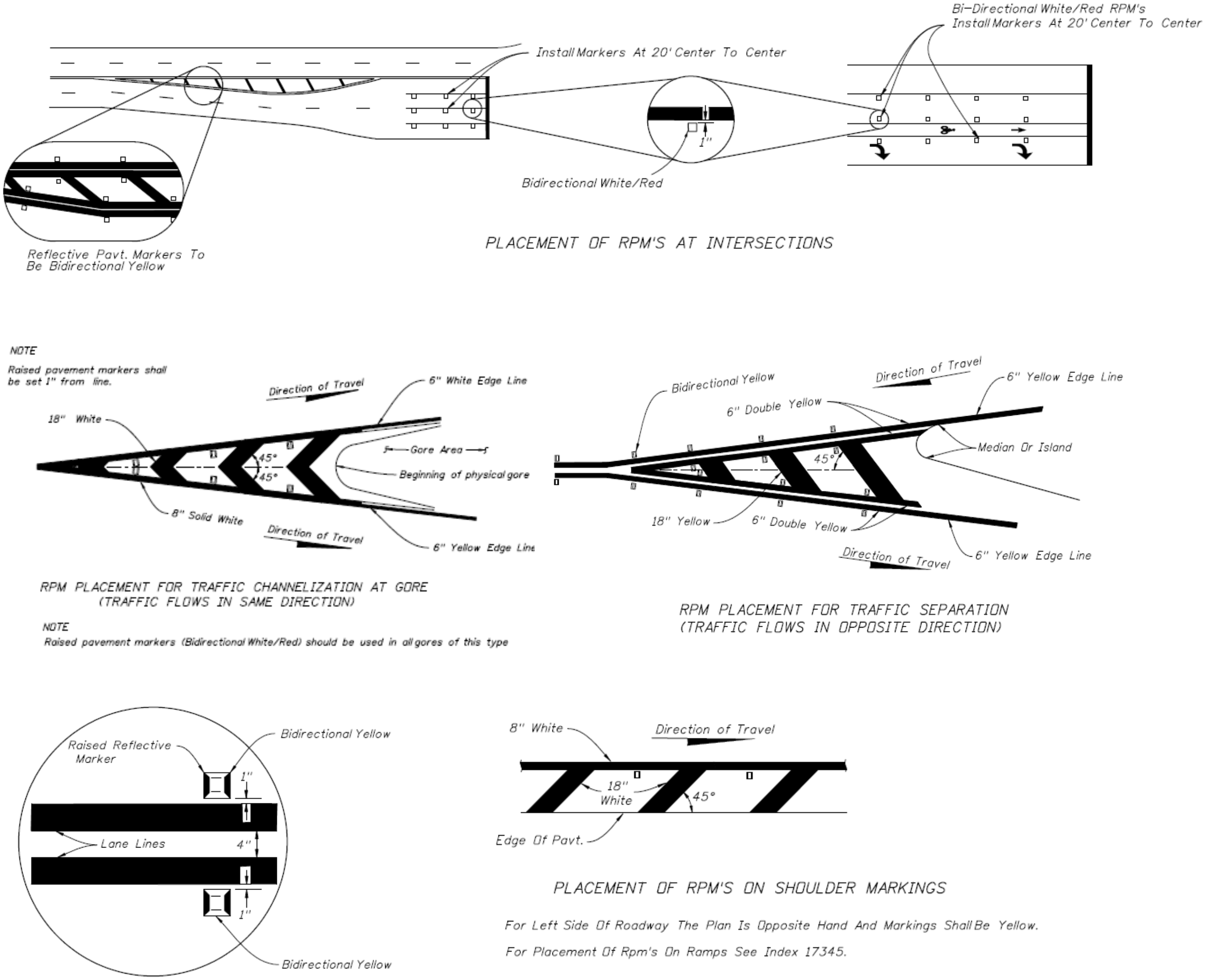


Figure 10 FDOT Standard Index Guidance for Placement of Raised Pavement Markers

Additional Reference Documents:

- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006). Index Number(s): 17352 and 17345.

- VicRoads. Traffic Management Note No. 20 – March 2005. *Use and Operation of Internally Illuminated Pavement Markers*. VicRoads Publication Number 01454. Victoria, Australia (2005).

- Khattak, Aemal and Bhaven Naik.. *The Use of Raised Pavement Markings in Work Zone Applications – A synthesis of Practice*. Smart Workzone Deployment Initiative, Kansas Department of Transportation. University of Nebraska (2006).

Treatment: LED Lights Embedded in Signs

Description

Light Emitting Diode (LED) Lights have previously been used as embedded objects in signs in Florida and are currently being evaluated in stop signs in Virginia and other states. Due to the small power requirement for the LED lights, they can be powered using stand-alone solar units similar to the illustration below.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Some data available, crash reductions uncertain
- **Estimated Effectiveness of the Treatment:** Medium
- **Crash Types Addressed:** Angle, Left-turn
- **Cost:** Low
- **Time To Implement:** Low

Anecdotal benefits include:

- Improving compliance with the stop sign
- Increasing the visibility of the stop sign especially under low-light conditions.

Applicability

This treatment is applicable at unsignalized intersections in either regulatory or warning signs, with the intended purpose of improving the visual conspicuity of the sign. Example applications include:

- Locations with sight visibility limitations (horizontal curves, dusk/dawn glare, etc.)
- Locations with documented problems with drivers failing to recognize an intersection.
- At stop signs, this treatment may help to increase the rate of vehicles stopping and to avoid vehicles failing to detect the sign.
- Due to the low power usage, solar applications make use of this treatment very flexible for nearly any location.

Figure 11 Example LED STOP Sign

Potential Safety Benefits

- Increase the visibility of intersections, particularly for night-time and low visibility conditions.
- Reduce instances of vehicles failing to stop (blowing through the intersection) and vehicles not coming to a complete stop.
- Could be paired with a vehicle detection to flash when vehicles are approaching at an excessive rate of speed to provide an extra emphasis of the stop sign presence.

Potential Difficulties

- LED lights are not yet on the Approved Products List (APL) for Florida. An alternative device would include a standard post-mounted flashing beacon, mounted above or below the sign (or both).

Compatibility with State and National Design Standards

The Florida Department of Transportation Design Standards does not provide guidance on the design of LED lights embedded in signs within the state. The *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance on the design of LED lights embedded in signs within the United States.

- *Option*: "Light Emitting Diode (LED) units may be used individually within the face of a sign and in the border of a sign, except for Changeable Message Signs, to improve the conspicuity, increase the legibility of sign legends and borders, or provide a changeable message. Individual LED pixels may be used in the border of a sign (Section 2A.08)."
- *Standard*: "If used, the LEDs shall be the same color as the sign legend, border, or background. If flashed, all LED units shall flash simultaneously at a rate of more than 50 and less than 60 times per minute. The uniformity of the sign design shall be maintained without any decrease in visibility, legibility, or driver comprehension during either daytime or nighttime conditions (Section 2A.08)."
- Sign elements to be illuminated by LEDs (MUTCD Table 2A-1):
  - Symbol or word message
  - Portions of the sign border

Design Considerations

- Prior to use, designers should verify whether LED lights have been added to the approved product list for use with signs.
- When placing LED's into a sign face, the lights should follow MUTCD guidance for placement of the individual pixels within the border of the sign, with a color that is consistent with the area of the sign face to which the LED's are being added. For instance, white LED lights should be used if placed within the border area of a stop sign, and red LED lights if placed within the background area of a stop sign.
- The LEDs may be set to flash 24 hours a day, or be vehicle activated by traffic crossing a detection device.
- Initial tests by the Virginia Transportation Research Council used the following design considerations:
  - A flashing rate of 1 flash per second (consistent with the max allowable by the MUTCD).
  - An automatic dimming feature to reduce night brightness.
  - A 13.5 x 15 inch solar panel supplying a 4.8-volt NiMH 6-inch battery pack.
  - The 48 inch sign was estimated at $1,860 plus $825 for post, anchor, and installation. The 36-inch and 30-inch sign assemblies were identified as slightly lower in price at $1,640 and $1,600 respectively (Arnold). All costs were reported as of year 2006.

STUDY RESULTS ON SAFETY EFFECTS OF LED LIGHTS EMBEDDED IN SIGNS

Study by: Texas Transportation Institute
Results:

- A 28.9% reduction in vehicles not fully stopping
- A 52.9% reduction in vehicles blowing through the intersection

Reference: Gates, T.J., Carlson, P.J., and Hawkins, H.G., Jr. *Field Evaluations of Warning and ` Regulatory Signs with Enhanced Conspicuity Properties*.

Study by: Virginia Transportation Research Council
Year: 2007
Results:

- Relatively small, yet statistically significant, decreases in vehicle speeds; ranged from 1.9 to 3.4 mph with an average of 2.7 mph, a 7% decrease
- Greater positive impact at night than day
- Reductions in approach speeds indicate that the LED stop signs caught the drivers' attention

Reference: Arnold, Jr., E.D. and Lantz, Jr., K.E. *Evaluation of Best Practices in Traffic Operations and Safety: Phase 1: Flashing LED Stop Signs and Optical Speed Bars.*

Maintenance

- “A regular schedule of replacement of lighting elements for illuminate signs should be maintained” (Section 2A.22, MUTCD).

Additional Reference Documents:

- Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C. (2003).
- Arnold, Jr., E.D. and Lantz, Jr., K.E. *Evaluation of Best Practices in Traffic Operations and Safety: Phase 1: Flashing LED Stop Signs and Optical Speed Bars*. Virginia Transportation Research Council. Charlottesville, Virginia (2007).
- Gates, T.J., Carlson, P.J., and Hawkins, H.G., Jr. *Field Evaluations of Warning and Regulatory Signs with Enhanced Conspicuity Properties*. Transportation Research Record 1862. Transportation Research Board, Washington, D.C. (2004). Pp. 64-76.

Treatment: Post-mounted Flashing Beacons

Description

Post-mounted flashing beacons may be used to increase the conspicuity of a regulatory or warning sign. The additional emphasis provided by the beacons may improve motorist compliance with stop signs. Although flashing beacons are a treatment commonly used, by combining the beacons with vehicle detection, standard flashing beacons can be used in an innovative way. Beacons are placed above or below the sign and may be configured using either one or two beacons.

Post mounted beacons are preferred to overhead beacons. Overhead beacons are being phased out in some states due to driver confusion regarding the meaning of the overhead beacon – which can be mistaken as a traffic signal.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** Level 1 for non-actuated, Level 2 for actuated
- **Quantity of Known Research Data:** Some data available, crash reductions unknown
- **Estimated Effectiveness of the Treatment:** Low for continuous flashing beacons. Medium for vehicle-actuated beacons
- **Crash Types Addressed:** Angle, Left-Turn, Speed, Visibility, Rear-End
- **Cost:** Low to Medium
- **Time To Implement:** Medium

Anecdotal benefits include:

- Improving motorist awareness by emphasizing regulatory and warning signs
- Increasing motorist compliance with stop signs.

Applicability

The use of flashing beacons is applicable at any unsignalized intersection. Beacons may be particularly useful at locations with a history of motorists failing to stop, locations with limited intersection visibility, or where special emphasis is required.

An innovative use of flashing beacons within Florida utilizes vehicle detection to activate flashing red beacons on stop signs within the median to encourage two-stage gap acceptance from the minor street. Loop detectors placed at the stop line simultaneously activate the red beacons within the median as well as flashing yellow beacons on advance warning sings on the uncontrolled highway approaches. Additional information regarding this treatment is provided in Case Study 1 in Appendix A.

Figure 12 Example Vehicle Actuated Flashing Beacons

Potential Safety Benefits

- Increase conspicuity of warning and regulatory signs.
- Improve awareness of the intersection on the uncontrolled approaches, which could lead to a reduction in angle and rear-end collisions.

Maintenance

- The addition of the flashing beacons will require a power source to the site; however solar powered units are available. Periodic maintenance of the beacons to replace bulbs, etc. is expected to be similar to that of a traffic signal display.

Compatibility with State and National Design Standards

The Florida Department of Transportation Design Standards does not provide guidance on the design of post-mounted flashing beacons within the state. However, the FDOT Traffic Engineering Manual (TEM) does provide specifications for the flashing mode of the beacons.

- Beacons should meet the requirements of the MUTCD and all new beacons should be installed with dual indications. Dual indications, wherever possible should be positioned laterally within each approach width to the intersection and shall be no closer than 8 feet apart measured horizontally.
- Dual indications for flashing beacons shall be flashed simultaneously.
- Dual bouncing ball flashing beacons (2 section heads mounted on one post) may be used in rare occasions where special impact is required at a high-crash intersection.

The *Manual on Uniform Traffic Control Devices* (MUTCD) provides guidance on the design of post-mounted flashing beacons within the nation.

Figure 13 Example Vehicle Actuated Advance Warning Beacons

General Design and Operation of Flashing Beacons

- *Guidance*: "If used to supplement a warning or regulatory sign, the edge of the beacon signal housing should normally be located no closer than 300 mm (12 in) outside of the nearest edge of the sign" (Section 4K.01).
- *Option*: "An automatic dimming device may be used to reduce the brilliance of flashing yellow signal indications during night operation" (Section 4K.01).

Warning Beacon

- *Standard*: "A Warning Beacon shall consist of one or more signal sections of a standard traffic signal face with a flashing CIRCULAR YELLOW signal indication in each signal section (Section 4K.03)."
- *Standard*: "A Warning Beacon shall be used only to supplement an appropriate warning or regulatory sign or marker. The beacon shall not be included within the border of the sign except for SCHOOL SPEED LIMIT sign beacons (Section 4K.03)."
- *Standard*: "Warning Beacons, if used at intersections, shall not face conflicting vehicular approaches (Section 4K.03)."

Stop Beacon

- *Standard*: "A Stop Beacon shall consist of one or more signal sections of a standard traffic signal face with a flashing CIRCULAR RED signal indication in each signal section. If two horizontally aligned signal lenses are used, they shall be flashed simultaneously to avoid being confused with a highway-rail grade crossing flashing- light signals. If two vertically aligned signal lenses are used, they shall be flashed alternately (Section 4K.05)."
- *Standard*: "The bottom of the signal housing of a Stop Beacon shall be not less than 300 mm (12 in.) nor more than 600 mm (24 in.) above the top of a STOP sign (see Section 2B.04) (Section 4K.05)."

Speed Limit Sign Beacon

- *Standard*: "A Speed Limit Sign Beacon shall be used only to supplement a Speed Limit sign (Section 4K.04)."

- *Standard*: "A Speed Limit Sign Beacon shall consist of one or more signal sections of a standard traffic control signal face, with a flashing CIRCULAR YELLOW signal indication in each signal section. The signal lenses shall have a nominal diameter of not less than 200 mm (8 in.). If two lenses are used, they shall be vertically aligned, except that they may be horizontally aligned if the Speed Limit (R2-1) sign is longer horizontally than vertically. If two lenses are used, they shall be alternately flashed (Section 4K.04)."

Design Considerations:

- The use of two beacons per approach may provide an increased level of visibility to motorists.
- Placement of the two beacons in a vertical fashion , above and below the sign, is a configuration commonly seen.
- The FDOT Traffic Engineering Manual specifies that the alternating flashing of dual indications is reserved for railroad approaches. However, this is typically a horizontal configuration. Using an alternating flashing pattern for beacons positioned vertically (above and below the sign) may be permissible – consistent with MUTCD guidance.
    - An existing installation on SR 20 uses two beacons positioned above and below the sign. The beacons are vehicle actuated and are flashed in an alternating pattern, which provides additional emphasis. Additional information on this treatment is provided in Case Study 1 in Appendix A.

Additional Reference Documents:

- Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C. (2003).

- Florida Department of Transportation. *Traffic Engineering Manual*. FDOT Manual Number 750-000-005. Tallahassee, FL (1999).

Treatment: Dynamic Speed Signs

Description

Dynamic speed indication signs are fairly commonplace in most states. Law enforcement officers use small trailer mounted units to provide visual feedback to drivers of their actual speed relative to the posted speed. These signs have also been used at horizontal curves, work zones, and other areas requiring speed reductions. The signs are activated by vehicles that exceed a predetermined speed (typically in excess of the posted speed limit) or by potential vehicle conflicts at the intersection. This type of sign is not intended to enforce the speed limit, but rather it is assumed that drivers will reduce their speeds once brought to their attention (Maze, 2000).

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Some data available, crash reductions uncertain
- **Estimated Effectiveness of the Treatment:** Not yet experimented with on multi-lane roadways.
- **Crash Types Addressed:** Speed, Visibility
- **Cost:** Medium to High
- **Time To Implement:** High

Applicability

Dynamic speed signs have been shown to significantly impact speeds on horizontal curves and in work zones; however the placement of the device can impact its effectiveness. Dynamic Speed signs may be used in advance of an intersection as part of a speed reduction, or could be incorporated into an Intersection Ahead warning sign – similar to signs being tested in Washington State (as shown in Figure 15 on the following page). When coupled with a warning sign, the dynamic speed/warning combination is expected to raise awareness of the approaching intersection and provide active notification to drivers to slow down.

Potential Safety Benefits

There has been no identified documentation of safety benefits associated with placing dynamic speed signs upstream of an intersection. NCHRP Project 3-74, *Guidelines for Selection of Speed Reduction Treatments at High Speed Intersections*, studied the effectiveness of dynamic speed signs on reducing vehicle speeds at three high-speed intersection locations. A mean speed reduction of 1.7 mph was observed after a three-month acclimation period at the actual sign location. Upstream, at the perception/reaction point, speeds were reduced by 2.3 mph. At the point of accident avoidance upstream of the sign, speeds were reduced by 2.8 mph. Each of these speed reductions was found to be significant (NCHRP Project 3-74).

Anecdotally, speed reductions within the intersection area may have a direct impact on intersection safety. Reduced speeds allow for an increased time for perception and reaction to conflicting vehicles. Additionally, slower travel speeds may result in fewer severe collisions.

Figure 14 Dynamic Speed Sign

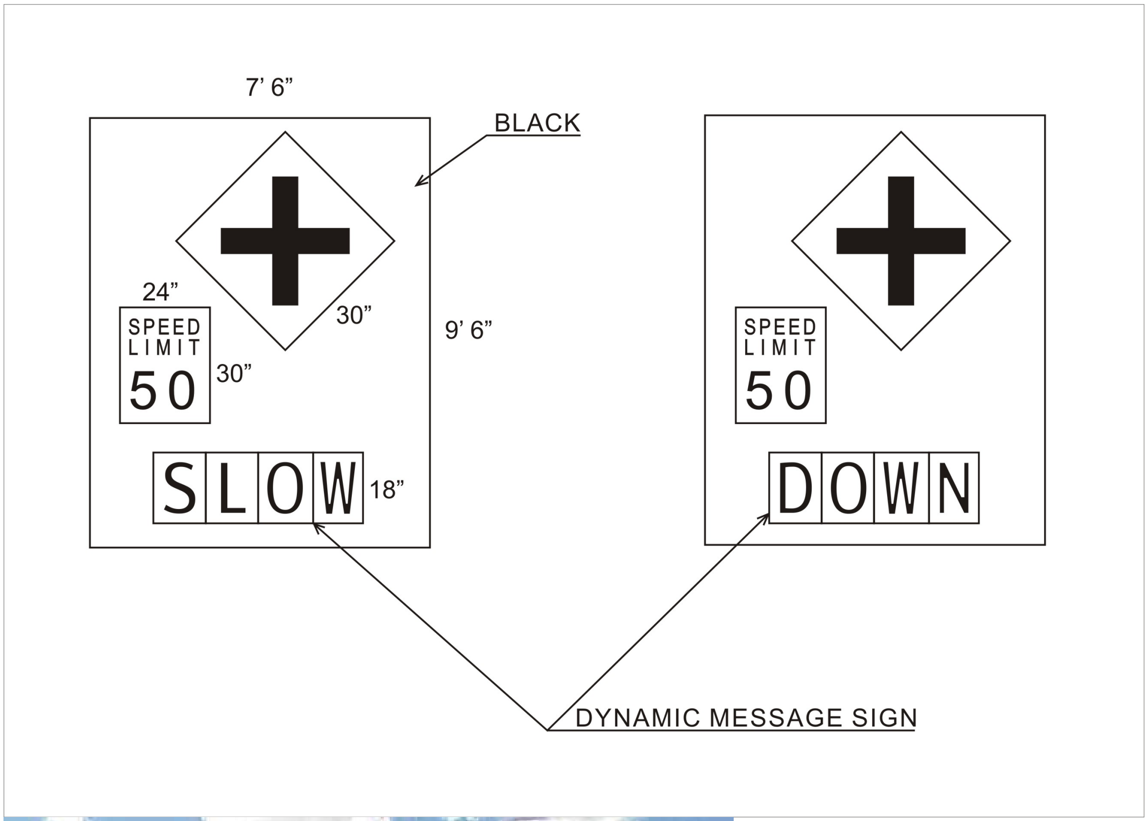


Figure 15 Combination Speed/Warning Sign – Othello, WA

Potential Difficulties

- Cost
- Maintenance

Design Considerations

- The Washington State design (previous page) utilizes a two-post sign that combines an intersection warning, speed advisory, and dynamic warning display that flashes the message “SLOW” - “DOWN” to drivers that are exceeding a specified speed threshold. Results of the test are not yet available. The uniqueness and complexity of this sign may result in a higher cost of implementation. This device would also require approval on the FDOT Approved Products List prior to use in Florida.
- Vertical and horizontal alignments of the roadway must be considered to allow for a clear sight line for the radar or video equipment. The permanent devices also require a nearby power source.
- The larger combination speed/warning signs are likely to be more applicable to rural applications where identification of the upcoming intersection may be as important as achieving a speed reduction. Due to the sign size, their application in an urban or suburban setting should be context sensitive.
- NCHRP Project 3-74 identified that determination of the maximum safe speed is one of the challenges of implementing these types of dynamic warning devices. For test installations conducted in Washington and Texas (see Figure 15), the maximum safe speed selected for both sites were higher than the posted speed limit.

Additional Reference Documents:

- Ray, B., W. Kittelson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, J. McGill, and D. Stewart. *Guidelines for Selection of Speed Reduction Treatments at High Speed Intersections*. NCHRP Web-Only Document 124, Contractors Final Report for NCHRP Project 3-74. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2007).

- Maze, T., A. Kamyab and S. Schrock. *Evaluation of Work Zone Speed Reduction Measures.* Center for Transportation Research and Education, Iowa State University: Ames, Iowa (2000).

Treatment: Roadside Markers

Description

One potential crash cause noted for high-speed roadways is the difficulty driver's face in judging oncoming vehicle speeds and selecting appropriate gaps. A lack of trees, poles, or other objects along the roadway can compound the situation since the driver has few points of reference with which to gauge the speed of oncoming vehicles. The Pennsylvania Department of Transportation in conjunction with Pennsylvania State University developed a static treatment for aiding drivers in determining sufficient gaps in conflicting traffic. Flexible markers were placed along the roadside in the intersection vicinity to provide points of reference for judging speed. Additionally, "X" markings were placed on the pavement as a guide to the waiting minor street drivers for when to enter the intersection. The "X" markings also provide a change in roadway conditions for the major street driver to raise awareness of the presence of an intersection.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** No data available
- **Estimated Effectiveness of the Treatment:** High, Known reductions to overall crashes and serious injury crashes
- **Crash Types Addressed:** Angle, Left Turn
- **Cost:** Low
- **Time To Implement:** Low to Medium

Anecdotal Benefits include:

- Improves information available to minor road drivers in selecting acceptable gaps.
- Increase awareness of the intersection and the potential for conflicting vehicles as drivers along the major roadway approach the intersection.

Figure 16 Pennsylvania DOT "Goal Post" treatment

Applicability

This treatment is primarily applicable to rural or suburban locations with a history of crashes caused by drivers misjudging approaching vehicle speeds or selecting gaps that are too small to safely complete the turn maneuver. The treatment is discouraged for an urban setting due to the potential for visual overload to drivers when combined with other roadway and roadside signs/markings.

Potential Safety Benefits

- The effectiveness of this treatment has not been quantified. The installation shown in the previous page was installed at only one location and was removed after a short time. A miscommunication in the implementation led to the removal of the treatment due to its installation prior to collection of before data. Without being able to assess the effectiveness of the treatment, the decision was made to end the experiment. It is unknown whether additional locations are being considered for further experiments with this treatment.
- Anecdotally benefits could include:
  - The treatment may reduce the instances of crashes by providing improved information to minor road drivers in selecting acceptable gaps.
  - Increase awareness of the intersection and the potential for conflicting vehicles as drivers along the major roadway approach the intersection.

Potential Difficulties

- Although the concept of the treatment has merit, there could be liability issues with vehicles traveling at excessive speeds on the major roadway. If a major road vehicle is traveling faster than the treatment is designed for, a sufficient gap may not be available for the minor street vehicle, even if the major road vehicle is not within the marked area.
- The use of an "X" pavement marking on the approach to the intersection may be mistaken for a railroad crossing. The use of the "X" marking at locations other than rail crossings could diminish its effect at rail locations, where it is intended to be used.

Design Considerations

- The distance upstream of the intersection for marker placement corresponded to the speed of oncoming vehicles and the time it would take to arrive at the intersection.
  - Speed studies should be conducted to identify median, and 85th percentile, and 95th percentile speeds.
- Signing should clearly convey the intent of the roadside markers and painted "X" markings on the roadway if designed to assist in gap acceptance.
  - The brief Pennsylvania DOT trial used a sign on the minor roadway indicating to drivers to wait to enter the intersection if a vehicle was within the marked area of the major road. The sign used was a white on black sign indicating a regulatory condition.
  - A yellow on black warning sign may be appropriate in lieu of a regulatory sign
- The roadside markers could be used simply as a passive device for giving drivers a reference for judging speeds where trees, poles, or other reference points are not present. In this situation, supplemental signing should not be used
- "X" markings are typically used at railroad tracks in conjunction with smaller "R" pavement legends on either side of the "X" to indicate railroad. FDOT Standard Index Drawing 17346 identifies that the "X" marking used for railroad applications are typically 8 feet wide by 20 feet long, although the width may vary depending upon the lane width. The markings are white and 16 inches in width.

Additional Reference Documents:

- None Identified

Treatment: Vehicle Actuated Variable Message Signs

Description

Advanced ITS systems have been implemented at unsignalized intersections by several states including Virginia, Maine, and Pennsylvania. These systems, coined "Collision Countermeasure Systems" and "Collision Avoidance Systems", are warning devices that instruct drivers of conflicting cross traffic to reduce angle and side-impact collisions. Graphical signs warn major roadway drivers of approaching minor road vehicles. Stops signs and activated graphical warning signs are provided for traffic on the minor roadway to identify the presence of cross traffic and the direction from which they are approaching.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 3
- **Quantity of Known Research Data:** Some data available, crash reductions uncertain
- **Estimated Effectiveness of the Treatment:** Not yet experimented with on multi-lane roadways
- **Crash Types Addressed:** Angle, Left Turn, Speed, Visibility
- **Cost:** Medium to High
- **Time To Implement:** High

Applicability

The ITS Systems identified as part of this project were all implemented on two-lane roadways – primarily to resolve sight distance issues. Although the treatment has not yet been installed on a multi-lane roadway, the concept has promise for portability to larger roads, especially in rural or suburban areas.

Potential Safety Benefits

ITS devices can be used to provide drivers with dynamic information on the presence of conflicting vehicles to help avoid potential collisions. The signs may result in speed reductions for vehicles on the major roadway and improved compliance with stopping on the minor street approaches.

In rural areas with high travel speeds, the problem of drivers identifying acceptable gaps is one of the primary safety issues. Systems are currently being tested in Minnesota that display oncoming vehicle speed or size of the available gap (in seconds) to minor street drivers (University of Minnesota).

STUDY RESULTS ON SAFETY EFFECTS OF VEHICLE ACTUATED VARIABLE MESSAGE SIGNS

Virginia (Prince William County)
Year: 2001
Results:

- Reduced intersection speeds through 1st year of operation
- Reductions in upper-percentile high-speed vehicles not sustained over time
- No side-impact crashes during the 2+ years while device was in operation – compared to 13 crashes (14 injuries) in previous five years.

Reference: Hanscom, Fred. *Evaluation of Prince William County Collision Countermeasure System.*

Maine (Norridgewock)
Year: 2001
Results:

- 35-40% reduction in intersection conflicts.
- Driver surveys identified the following public reactions:
  - 67% of respondents felt the signs would prevent crashes
  - 64% recommended use of the signs at other intersections.
  - 93% of survey respondents identified that they could see the signs clearly and understand its meaning (Peabody).

Reference: D. Peabody, P. Gardner, G. Audibet, W. Thompson, M. Redmond, and M. Smith. *Evaluation of a Vehicle-Actuated Warning System for Stop-Controlled Intersections Having Limited Sight Distances.*

Potential Difficulties

Although the control type for the intersection remains unsignalized, the dynamic signing and detection devices will require some of the same equipment typically required for a traffic signal including a controller and cabinet, loops or video detection devices, and LED message signs. Reported costs for such devices vary widely depending upon the complexity of the signs. The more ‘standard’ components that can be used will generally result in a lower cost.

Design Considerations

- Simple Design – These devices are not a common sight for most drivers. Care should be taken to ensure that the signs are clear and easily understood.
- Detection and sign placement are critical to the success of these ITS systems. The signs should be placed far enough in advance of the intersections to allow adequate time for an approaching driver to read the message and respond to a potential conflicting vehicle.
- Designs should have a fail-safe system built in. The systems implemented to date have a dynamic display that indicates to drivers when a conflicting vehicle is present. Drivers that regularly navigate through the intersection could become dependant upon the signs. In the event of a malfunction, in which no vehicle is displayed on the sign when A system implemented in Pennsylvania provided a battery back-up and displayed random dots on the signs to indicate a malfunction.

Example Applications

Virginia (Prince William County) Collision Countermeasure System

In 1998, the Virginia DOT implemented one of the first ITS systems of its type called the “Collision Countermeasures System” (CCS). The system was installed at a rural two-way stop controlled intersection that had a history of crashes due to restricted sight distance. The ITS devices included vehicle activated dynamic warning signs on both the major and minor road approaches to alert drivers of conflicting vehicles.

The warning signs are illustrated below. On the major roadway, pavement loops detect vehicles approaching the intersection and activate a warning sign on the minor roadway that illustrates the direction of the approaching vehicle. When a vehicle is stopped at the stop sign on the minor roadway, a pavement loop detector activates a sign on the major roadway to indicate “Traffic Ahead” and the side of the intersection that has a waiting minor street vehicle. The system does not indicate when a safe crossing is available, but merely warns drivers that a conflicting vehicle is present.

A study of the Virginia DOT test site found that the CCS system resulted in (1) lower intersection-approach speeds following installation and after 1-year; (2) longer projected times to collision; (3) reductions in the upper percentile high-speed vehicles were not sustained over time. No side-impact crashes were reported at this intersection during the time that this device was in operation compared to 13 accidents (14 resulting injuries) in the five years preceding the implementation (Hanscom, 2001). Virginia DOT removed the CCS system in 2000 due to maintenance concerns, however they are currently reconsidering installation at another site.

Figure 17 Prince William County (Virginia) Collision Countermeasure System

(Source: Virginia Transportation Research Council)

Maine Vehicle Actuated Warning System

In Norridgewock, Maine, the Maine Department of Transportation installed a pilot project implementation of a vehicle actuated warning system in early 2001 (Peabody, 2001). A concrete arch bridge immediately south of the intersection limits sight distance to the intersection. Signs on the minor roadway warn drivers waiting at the stop sign when traffic is approaching from either direction. Another warning sign located on the blind side of the major approach warns drivers of vehicles waiting at the stop sign on the minor roadway. The dynamic warning sign on the major road approach had been in place for several years prior to the full intersection implementation. Warning signs are triggered by loop detectors. The cost of the system in year 2001 was approximately $31,000 for materials and installation.

Figure 18 Vehicle Actuated Warning System (Norridgewock, Maine)

A conflict analysis was used to evaluate the Maine intersection before and after the treatment installation. The evaluation identified a 35-40% reduction in intersection conflicts. Driver surveys identified positive feedback as well, with 67% of respondents identifying that they felt the signs would prevent crashes and 64% recommending use of the signs at other intersections. 93% of survey respondents identified that they could see the signs clearly and understand it's meaning (Peabody, 2001).

Pennsylvania Collision Avoidance System

The Pennsylvania Collision Avoidance System (CAS) is an ITS traffic control device to advise drivers of conflicting crossroad traffic. The systems were implemented in 2001 and are similar to the Virginia CCS system which was the only U.S. application constructed at the time. The CAS system was designed for application at two unsignalized, stop-controlled rural intersections in Butler County, Pennsylvania primarily due to limited site distance and high vehicle speeds at these locations. Actively illuminated signs, operating on input from vehicle-detection pavement loops, automatically warn drivers of conflicting crossroad traffic approaching the intersection. Drivers approaching the intersection from all directions are graphically advised of the presence and direction of approaching intersection traffic. Costs for the system in year 2001 were cited at approximately $370,000 to construct the system at two locations and $10,000 for design.

Advance Warning Sign

Intersection area warning sign

Figure 19 PennDOT CAS Major Road Warning Signs.

Figure 20 PennDOT CAS Minor Road Display of Approaching Major Road Vehicles

Maintenance, liability, and fail-safe mechanisms were primary concerns among those surveyed. The original Virginia DOT CCS system did not have a failsafe mechanism and relied upon reporting from the public for outages. The system had to be manually reset and had a blank display during a malfunction operation. Based upon the survey discussions, future implementations of the CCS system in Virginia will include a solar-powered battery back-up system. Several of the individuals surveyed indicated a concern about the malfunction situations and the potential liability that could exist without a failsafe. As drivers become familiar with the devices, they become more conditioned to rely on the signs to identify safe conditions. If the sign does not detect a vehicle or does no perform as expected, there is potential for a crash due to drivers relying too heavily on the sign messages.

Both the Maine and Pennsylvania systems included a default mode for a malfunction or power outage condition. In the Maine system, the vehicle symbols continuously flash in an alternating fashion during a malfunction. However, in the event of a power outage, the vehicle indications are blank and the static "Vehicles Approaching" sign is all that is visible. The Pennsylvania system provides an 8-hour battery back-up in the event of a power failure. In the event of a malfunction, the system display continuously flashes 'garbage' (which is comprised of random pixels being illuminated) to indicate to drivers that they system is not working properly. PennDOT has identified two instances of a malfunction: one occurred when a pavement loop broke and another occurred when a utility vehicle parked on the loop for an extended period of time. PennDOT identified that they allocated a monthly maintenance budget to provide maintenance funding of the devices.

Additional Reference Documents:

- Hanscom, F. R. *Evaluation of the Prince William County Collision Countermeasure System*. Paper VTRC 01-CR5. Virginia Transportation Research Council: Charlottesville, VA (2001).
- Peabody, D., P. Garder, G. Audibet, W. Thompson, M. Redmond, and M. Smith. *Evaluation of a Vehicle-Actuated Warning System for Stop-Controlled Intersections Having Limited Sight Distances*. 2001 International Conference on Rural Advanced Technology and Transportation Systems (2001).
- Pennsylvania Department of Transportation. *Crash Avoidance System Summary Information.* Pennsylvania Partnership for Highway Quality 2004 Awards Program, Safety Award. (2004).
- University of Minnesota, Intelligent Transportation Systems Institute. *Intersection Decision Support System*. Two-Page Brochure. www.its.umn.edu/research/applications/ids (Accessed April 2007).
- Maze, T.H., N. Hawkins, and G. Burchett. *Rural Expressway Intersection Synthesis of Practice and Crash Analysi*s. Center for Transportation Research and Education, Iowa State University (2004).

Description

Rumble strips are raised or grooved patterns installed on the roadway that create a texture different from pavement so as to produce both an audible warning and physical vibration when vehicle tires pass over them. Transverse rumble strips are installed across the travel lanes of the roadway, perpendicular to the flow of vehicles. Potential applications include approaches to intersections of expressways, rural highways, and parkways to reduce approach vehicle speeds and prevent intersection crashes (NCHRP Project 3-74).

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 1
- **Quantity of Known Research Data:** Some data available, crash reductions known but not uncertain
- **Estimated Effectiveness of the Treatment:** Medium
- **Crash Types Addressed:** Rear-End, Speed Related, Stop Sign Compliance, Intersection Visibility/Driver Attention
- **Cost:** Low to Medium
- **Time To Implement:** Low to Medium

Applicability

Transverse rumble strips are typically installed on the approach to an intersection and are intended to call attention to the presence of an intersection or an action, such as a warning for a stop ahead. Transverse rumble strips are often used in conjunction with warning signs to emphasize the purpose or message of the rumble strip and should be placed where the traffic control device is in view of the alerted motorist (NCHRP Project 3-74). In a survey conducted as part of the current project, survey participants indicated the desire for the message of a rumble strip to be uniform system wide.

Figure 21 Thermoplastic Transverse Rumble Strips

Transverse rumble strips are also used before toll plazas, horizontal curves, railroad crossings, or road divergences to warn drivers to slow down. Normally, transverse rumble strips are only considered at locations where a documented accident problem exists such as rear-end accidents and ran-STOP-sign accidents involving an apparent lack of driver attention. Usually, more conventional treatments such as signing are applied first (Corkle, 2001).

Potential Safety Benefits

There are numbers of potential safety benefits associated with the implementation of transverse rumble strips including reducing crashes, alerting drivers, improving sign effectiveness, and increasing the rate of deceleration of vehicles.

- **Reducing crashes:** Rumble strips on intersection approaches can reduce rear-end collisions and ran-stop-sign collisions by up to 50 percent (NCHRP Report 500). The reduction is related to only those crash types that are susceptible to correction by rumble strips, not the overall intersection. The use of rumble strips may also reduce right-angle accidents, which are commonly associated with running through a stop sign or signal, by alerting drivers to an upcoming condition (Carlson, 2003).
- **Alerting drivers:** In-lane rumble strips have the potential to be effective for alerting drivers who are sleep deprived, under the influence of alcohol, or driving in poor conditions (Corkle, 2001).
- **Alerting drivers:** In Australia, full transverse pavement markings are sometimes used upstream of changes in the roadway cross-section (such as a transition from four lanes to two lanes). The markings are white preformed thermoplastic and are placed approximately 50’ to 100’ apart for a distance of ¼ to ½ miles upstream of the transition point. This treatment could be effective at an unsignalized intersection to aid in driver recognition of the intersection (Information based upon survey responses conducted at part of this project).
- **Improving sign effectiveness:** Transverse rumble strips may greatly increase the percentage of drivers making a full stop at a STOP sign
- **Increasing the rate of deceleration of vehicles:** Generally, transverse rumbles do not have a significant effect on reducing speed. However they have been found to affect the rate of deceleration to get drivers to brake harder early in the braking maneuver. However, drivers began to slow down and finished braking at the same times whether rumble strips were present or not (Harder, 2003).

Effectiveness of the Treatment

- Research identified on the topic of rumble strips was generally inconclusive with regard to effectiveness of this treatment. NCHRP Synthesis 191 identified that previous studies generally indicate that rumble strip installation in the travel lane can be effective at reducing accidents. However the study results are not reliable enough to quantify the expected accident effectiveness. Placement of rumble strips in the travel lane should be considered only where a documented accident problem exists and only after more conventional treatments, such as signing, have been tried and found to be ineffective (Harwood, 1993).
- States surveyed as part of this project identified limited speed-reduction benefits from the transverse rumbles and primarily cited their use for alerting drivers of the need to stop.
- Research by Kermit and Hein (1962) found that rumble strip installation increase the percentage of drivers making a full stop at the stop sign from 46 to 76 percent, and the percentage of drivers making a full or partial stop in increased from 96% to 100%.
- The Iowa Department of Transportation provides rumble strips at approximately 90% of the stop controlled intersections on the state system. The rumble strips are only installed on the roadway approaches that will stop. This was intentionally done to provide drivers with a consistent message that rumble strips mean that a stop is ahead.
- Transverse pavement markings were tested by Kansas DOT. During a phone interview, KDOT staff identified that they found the markings did not provide a significant benefit in terms of speed reductions and therefore have not been used in the state.
- Research by the Texas Transportation Institute found that transverse rumble strips produce very small reductions in speed. A study of five intersections found that only three of the site displayed speed reductions greater than one mph (Thompson, 2006). This research did not evaluate the impact of rumble strips on compliance with a Stop sign, nor did it examine the safety impact derived from alerting drivers.

Potential Drawbacks

There are a few considerations to using transverse rumble strips that should be taken into account when evaluating a potential site. These include noise disturbances, impacts on bicycles and motorcycles, potential for driver-avoidance, and maintenance.

- **Noise:** Noise from vehicles driving over transverse rumble strips may disturb nearby residents (NCHRP 500). Care should be taken when selecting sites for implementation of rumble strips to avoid locations with nearby residential uses. In rural environments, rumble strips were identified as causing disturbances to livestock in close proximity to the devices.
- **Negative impacts on bicycles and motorcycles:** Riders can easily be startled by the vibrations generated when crossing transverse rumble strips. This can cause riders to maneuver quickly to avoid the in-lane rumble strips and potentially swerve into oncoming traffic or off the road completely (NCHRP Project 3-74).
- **Driver-avoidance:** A potential problem exists regarding drivers not wanting to drive over rumble strips that they know are approaching. "Some motorists may avoid driving over the in-lane rumble strips by straddling them, by driving on the shoulder, or by moving into opposing traffic (Corkle, 2001)."

Design Considerations

The design of the transverse rumble strips can play a large role in the safety and operational performance of the treatment. Considerations for the designs will be identified where applicable. Where significant design guidance is required, reference documents will be noted for further guidance to engineers.

- **Use sparingly** to retain element of surprise for motorists (NCHRP 500).
- **Rumble strips should be located in the vicinity of a warning sign,** such that the sign and the rumbles work together to provide additional emphasis of the upcoming intersection.
- Discussions with Texas DOT identified a preference for raised pavement marking rumbles which provide more **retro-reflectivity and visibility**.
- Two types of transverse rumble strips can be installed: **full width or wheel track**. Wheel track rumble strips are shorter and are only provided within the normal wheel path. These types of rumbles may be more prone to driver avoidance maneuvers.
- **Easy to install.** Time for implementation is 3 months or less (NCHRP 500).
- **Relatively inexpensive** Normal cost of implementation is nominal (NCHRP 500).
- **Relatively low cost** treatment. Approximate cost was cited as $500 to $1,000 for two intersection approaches for raised rumble strips (Corkle, 2001).
- Iowa DOT uses **milled in rumble strips within a concrete pavement** surface to reduce maintenance. However, in Iowa, snow plowing creates a serious maintenance concern for raised rumble strips since the snow plows may literally scrape the rumble strips off the pavement. This is less of an issue in Florida where snow is rare.

Compatibility with State and National Design Standards

The FDOT Standard Index 518 provides guidance on the design and placement of rumble strips on state roadways. The figures shown below illustrate this guidance. Transverse rumble strips within the roadway should be of the raised type, constructed in accordance with Section 546 of the FDOT specifications. Either thermoplastic or asphalt rumble strips are currently identified in the Standard Index as options, however as noted below, the spacing of the rumbles varies for the two different materials. Rumble strips should be provided in sets of gradually decreasing spacing on the approach of an intersection.

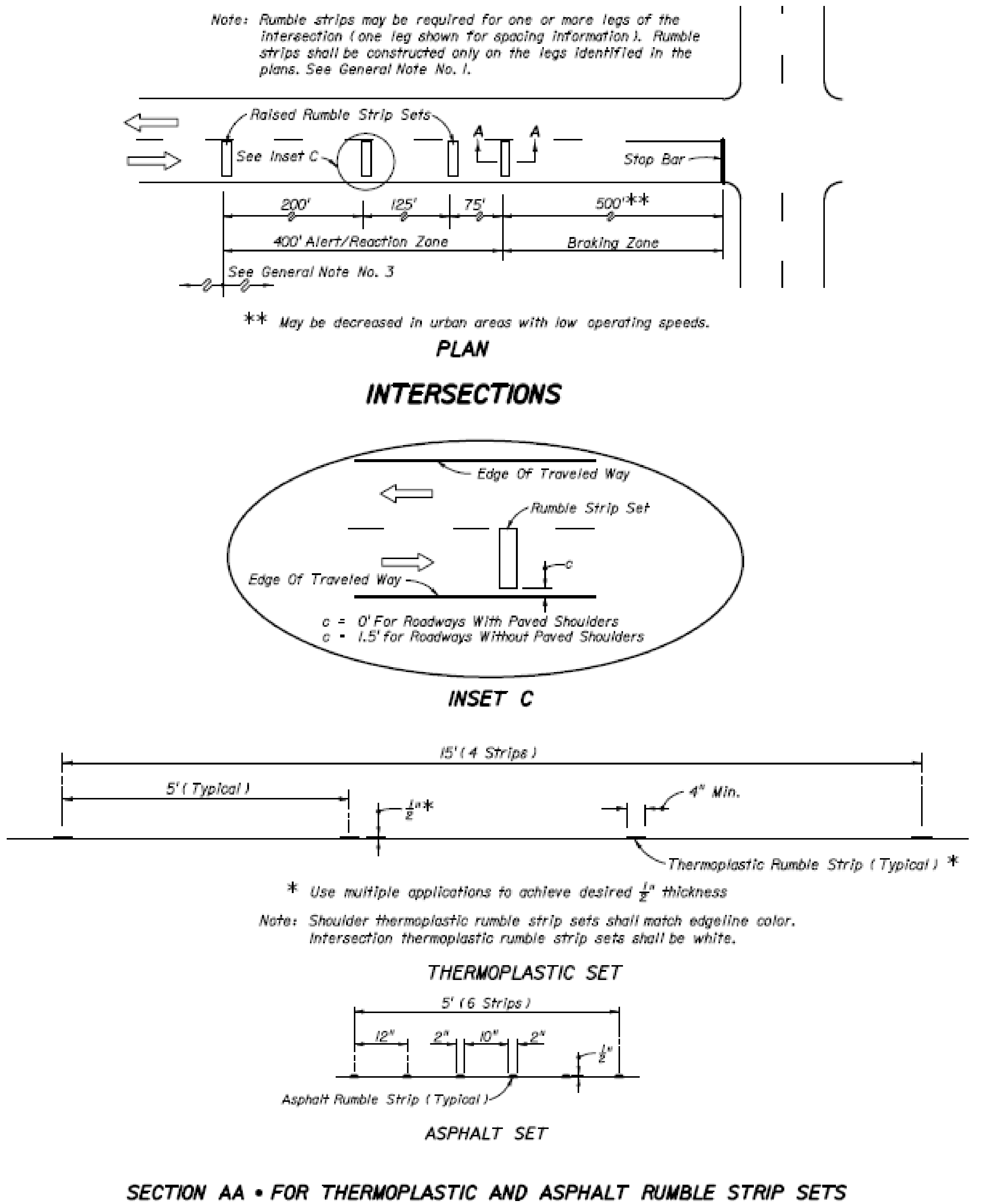


Figure 22 FDOT Standard Index 518 Guidance for Rumble Strips

Treatment: Transverse Rumble Strips (Continued…)

Maintenance

- During resurfacing, both milled in and raised thermoplastic rumble-strips will require replacement.
- The Iowa Department of Transportation identified that a key to preventing premature degradation is to use concrete panels at the locations of the rumble strips and have the rumble strips milled into the concrete.
- The Texas Department of Transportation identified that the raised, pavement marking type rumble strips are high maintenance. On average, replacement of the raised thermoplastic rumble strips is required approximately every 6 months.
- Raised rumble strips constructed out of asphalt and then covered in thermoplastic may provide a longer life between maintenance.
- There is no evidence that the presence of rumble strips causes quicker pavement deterioration (Corkle, 2001).

Additional Reference Documents:

- National Cooperative Highway Research Program (NCHRP). *Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. Transportation Research Board, Washington D.C. (2003).
- Carlson, Paul and Jeff Miles. Effectiveness of Rumble Strips on Texas Highways: First Year Report. FHWA/TX-05/0-4472-1. Texas Transportation Institute for Texas Department of Transportation. Austin, TX (2003).
- Corkle, J., M. Marti, and D. Montebello. "Synthesis on the Effectiveness of Rumble Strips." *Report No. MN/RC-2002-07* Minnesota Department of Transportation: St. Paul, MN (2001).
- Harwood, D.W. *NCHRP Synthesis of Highway Practice 191: Use of Rumble Strips to Enhance Safety*. Transportation Research Board, National Research Council: Washington, D.C. (1993).
- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006).
- Harder, K.A., J. Bloomfield, B.J. Chihak. *Crashes at Controlled Rural Intersection*. Report MN/RC-2003-15. Local Road Research Board, Minnesota Department of Transportation. (July 2003).
- Ray, B., W. Kittelson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, J. McGill, and D. Stewart. *Guidelines for Selection of Speed Reduction Treatments at High Speed Intersections*. NCHRP Web-Only Document 124, Contractors Final Report for NCHRP Project 3-74. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2007).
- Thompson, Tyrell, Mark Burris, and Paul Carlson. *Speed Changes Due to Transverse Rumble Strips on Approaches to High-Speed Stop Controlled Intersection*. Transportation Research Record 1973. Washington, D.C. (2006).
- Wisconsin Department of Transportation. *Gauging the Safety Effects of Rumble Strips at Rural Intersections*. Bureau of Highway Operations (July 27, 2007).

Treatment: Median Rumble Strips - Lane Narrowing

Description

A treatment currently being tested through an FHWA research project for Low-Cost Speed Reduction Concepts is the use of rumble strips and pavement markings to create a channelized island between the two travel directions along the major roadway. The median island effectively reduces the travel lane width from 12 feet to 9-10 feet at the intersection in an attempt to induce drivers to slow down. The treatment is design for two-lane roadways, which may limit it's effectiveness as a speed reduction technique for multi-lane roadways. However, there may be some safety benefits that would translate to multi-lane undivided roadways, including discouraging passing maneuvers in the intersection vicinity with the intent of reducing the instance of head-on collisions.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** No data available
- **Estimated Effectiveness of the Treatment:** Unknown
- **Crash Types Addressed:** Angle, Intersection Visibility
- **Cost:** Low
- **Time To Implement:** Low

Anecdotal benefits include:

- Improving motorist awareness of the intersection
- Increasing motorist compliance with stop signs.
- Preventing passing maneuvers and lane changes within the intersection vicinity

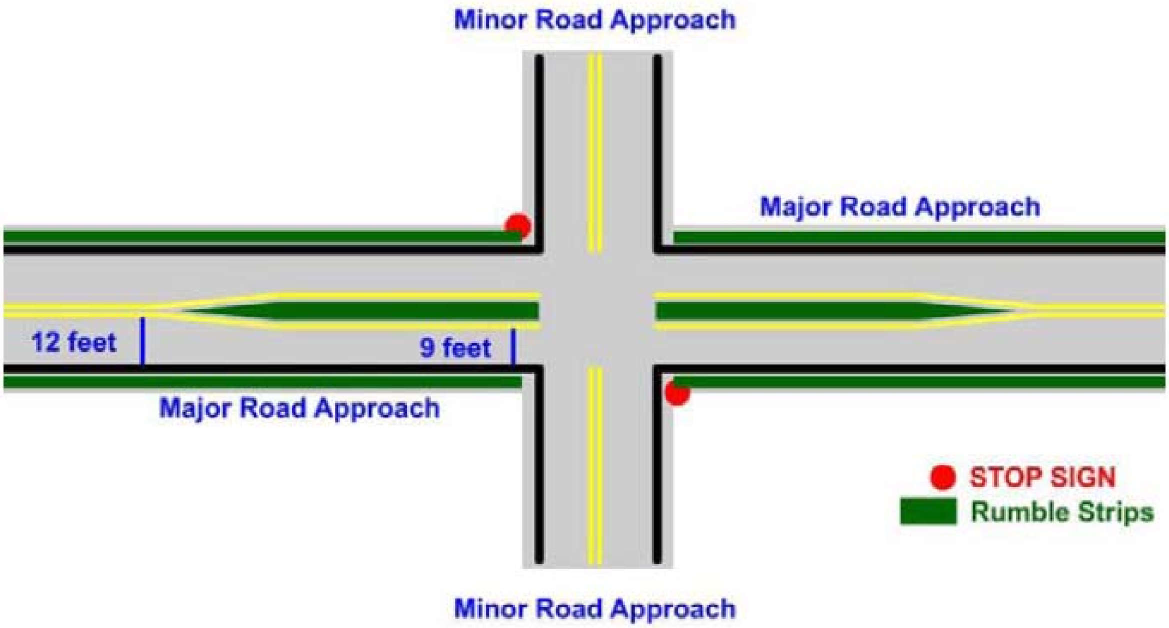


Figure 23 Centerline Median Rumble Strips for 2-Lane Roads (Source BMI-SG).

Applicability

- For multi-lane roadways, the median rumble strip treatment is not directly applicable except for undivided roadways, where the median rumble strips could be used to separate opposing traffic streams.
- The median rumble strips could be incorporated as a treatment on the minor road approach to multi-lane roadways. The treatment would likely be most effective where there is a history of crashes involving vehicles running the stop sign.
    - The median rumble strips may also provide benefit on curved roadways to discourage drivers from cutting across the inside of a curve (NCHRP Report 500).
- An extrapolation of the median rumble strip treatment for multi-lane divided roadways could to provide a similar lane narrowing by marking a set of chevrons into a narrow island along the roadway centerline in similar fashion as identified for the median rumble strips. An illustration of this concept is shown in Figure 24. The island could utilize raised type rumble strips made out of thermoplastic, or they could be simply painted. The length of the island would vary based upon design speed of the major roadway, with the intent to deter drivers from making lane change maneuvers within the intersection vicinity.

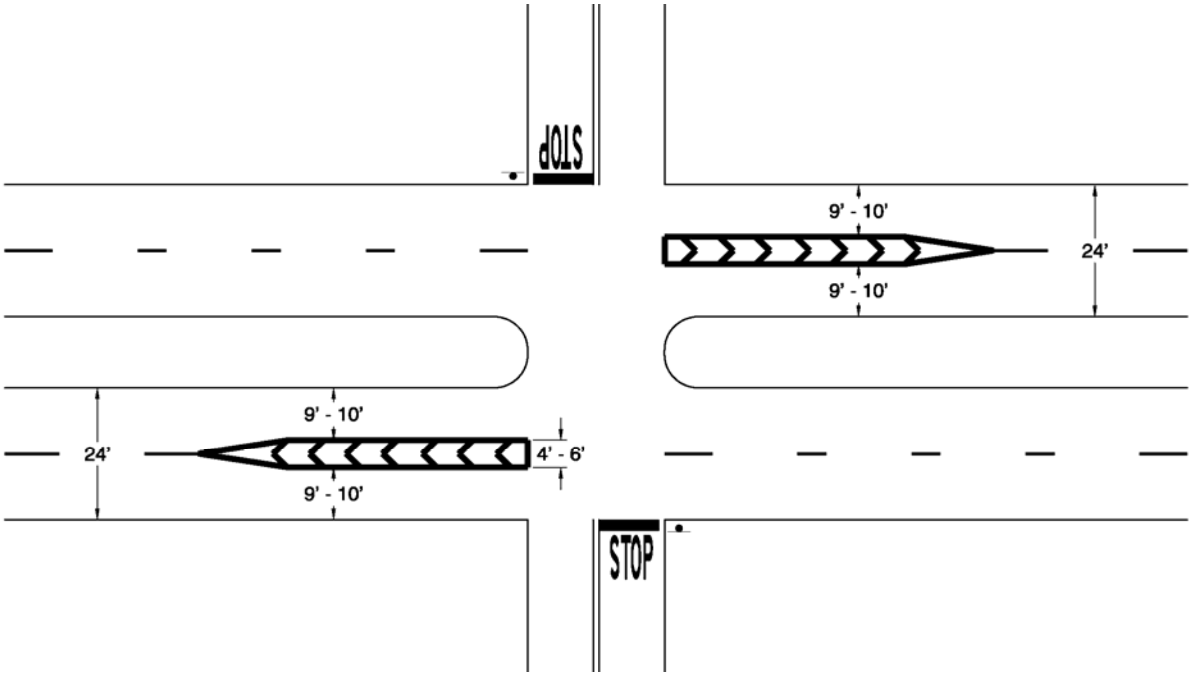


Figure 24 Lane Line Islands for Roadway Narrowing on Four-Lane Divided Roadway.

Potential Safety Benefits

- Safety data for the median rumble strip treatment is not yet available. Field tests of the treatment shown in Figure 23 are currently ongoing.
- Potential safety benefits include minor speed reductions in the vicinity of the intersection, eliminating passing maneuvers in the vicinity of the intersection, and raising driver awareness of the presence of an intersection.

Potential Difficulties

- Both the painted markings and rumble strips will require ongoing maintenance.
- If used on the minor street, large vehicles may be required to track across the rumble strips for left- or right turns from the major roadway. The rumbles may slow turning vehicles which could have an impact on major road operations.

Compatibility with State and National Design Standards

- The FDOT Standard Index 518 provides guidance on the design and placement of edgeline and transverse rumble strips on state roadways. No explicit guidance is provided related to median rumble strips.
- Transverse rumble strips within the roadway should be of the raised type, constructed in accordance with Section 546 of the FDOT specifications. Either thermoplastic or asphalt rumble strips are currently identified in the Standard Index as options.

Design Considerations

- Section 3.9 of the FDOT Intersection Design Guide provides guidance on minimum lane widths for FDOT facilities. The guidance general identifies 12 foot lanes as the minimum for arterial roadways, 11 foot lanes on collector roadways, and 10 foot lanes on local roadways. The localized narrowing's (as shown in Exhibit 2) would effectively reduce the travel lane width below the FDOT minimums; however the physical roadway width would remain the same.
    - For the case illustrated in Exhibit 2, it may be desirable to omit rumble strips and simply use painted markings to avoid physically reducing the effective lane width.
- Preliminary findings from NCHRP Project 3-72: Lane Widths, Channelized Right Turns, and Right-turn Deceleration Lanes in Urban and Suburban Areas indicates that reducing lanes widths to less than 9 feet on four-lane divided arterials (NCHRP Project 3-74).

Additional Reference Documents:

- Bauer, K.M., D.W. Harwood, W.E. Hughes, and K.R. Richard. "Safety Effects of Using Narrow Lanes and Shoulder Use Lanes to Increase the Capacity of Urban Freeways". *Paper 04-2678* presented at TRB 84th Annual Meeting: Washington, D.C. (2004).

- BMI-SG. Low Cost Speed Reduction Concepts research. *Preliminary Work Plan for Task 3. Technical Support to the FHWA Office of Safety* (2005).

- National Cooperative Highway Research Program (NCHRP). *Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. Transportation Research Board, Washington D.C. (2003).

- Ray, B., W. Kittelson, J. Knudsen, B. Nevers, P. Ryus, K. Sylvester, I. Potts, D. Harwood, D. Gilmore, D. Torbic, J. McGill, and D. Stewart. *Guidelines for Selection of Speed Reduction Treatments at High Speed Intersections*. NCHRP Web-Only Document 124, Contractors Final Report for NCHRP Project 3-74. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2007).

Treatment: Median Acceleration Lanes

Description

A median acceleration lane (MAL) is a dedicated lane that facilitates vehicles from the minor street to accelerate to free-flow speeds before merging into the primary travel lanes after making a left turn.

Applicability

The target for this strategy should be unsignalized intersections on divided highways that experiences a high proportion of rear-end collisions related to the speed differential caused by vehicles turning left onto the highway. Acceleration lanes may be also considered where intersection sight distance is inadequate or where there are high volumes of trucks entering the divided highway (NCHRP 500). At least one known location with a median acceleration lane currently exists in Tallahassee, Florida on US 319 (Thomasville Road). However this is not currently a common treatment within the state.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 3
- **Quantity of Known Research Data:** Some data available, crash reductions known but uncertain
- **Estimated Effectiveness of the Treatment:** Medium
- **Crash Types Addressed:** Rear-End, Side-swipe, and Angle
- **Cost:** High
- **Time To Implement:** Medium

Anecdotal benefits include:

- Reduced delay to minor street traffic. This reduces the likelihood of a motorist attempting to take a gap that is too small.
- Allows vehicles to accelerate to the same speed as the major roadway prior to merging. May be especially beneficial for locations with high percentages of trucks.

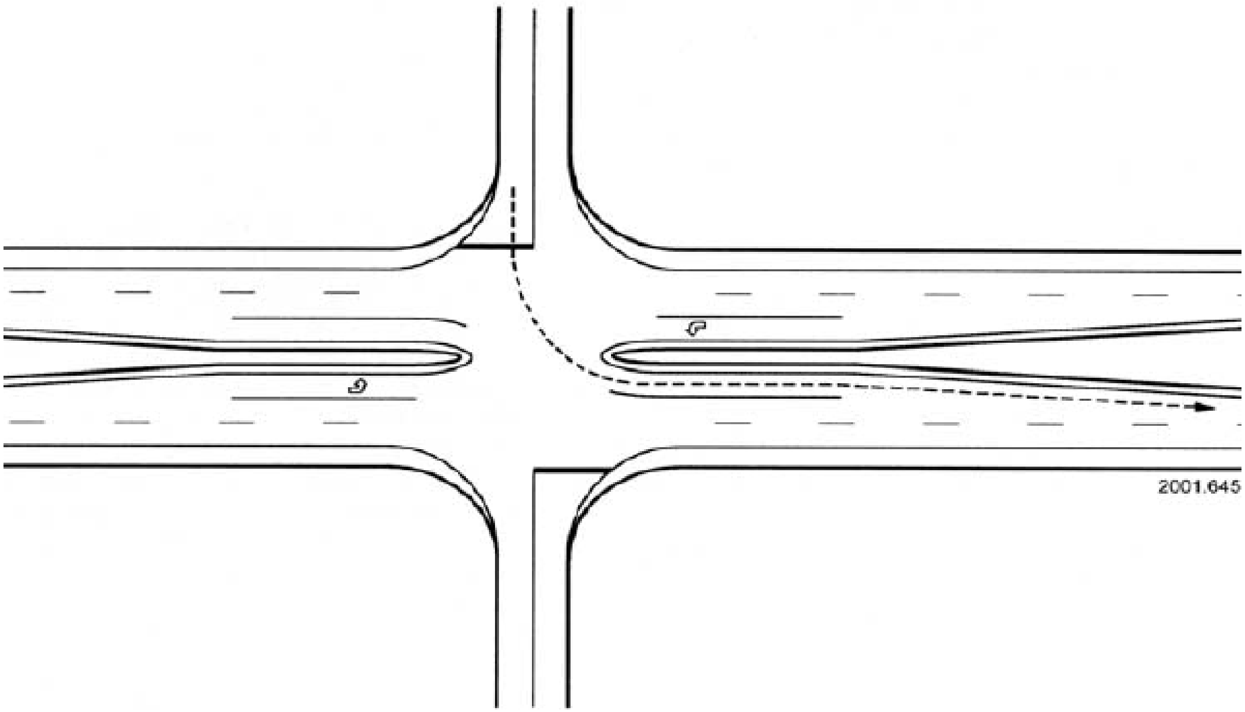


Figure 25 Median Acceleration Lane Illustration (Source: NCHRP 524)

Source: Google Earth

Figure 26 Median Acceleration Lane (Tallahassee, Florida)

Potential Safety Benefits

- This type of treatment will reduce the speed differential between vehicles which will help to prevent rear-end, sideswipe, and angle crashes. These collisions may occur as a result of though vehicles not being able to avoid the entering turning vehicles or from left-turn drivers incorrectly judging gaps (NCHRP 500).
- There are potential benefits associated with median acceleration lanes in areas with a high volume of trucks making left turns onto the major street. The treatment gives trucks more time to gain speed and merge into traffic.
- Research has shown that median acceleration lanes can function effectively and do not create safety problems (NCHRP 500).
- Median acceleration lanes can minimize the probability that larger vehicles will need to stop in the median opening area (NCHRP 524).

STUDY RESULTS ON SAFETY EFFECTS OF MEDIAN ACCELERATION LANES (MAL)

Study: Minnesota DOT
Year: 2002
Results:

- Decrease in delay for drivers due to reduced need to stop within the median to wait for a sufficient gap
  - Percentage of drivers waiting in median reduced from 74% to 4%
- Rear-end collisions dropped by 40%
- Rear-end crash rate was over 70% lower for medians with acceleration lanes compared to locations without them.
- Approximately 75% of preventable crashes that occurred at study locations were caused by drivers who did not use MALs at all.
- Poll of 200 users taken…
  - 95% of respondents identified that they usually or always use the MAL.
  - 70% thought that the MAL helped them merge 'very much'.

Reference: Hanson, Chad. *Median Acceleration Lane Study Report*. Mn/DOT District 6 Traffic Office.

- A 1982 ITE survey identified the following advantages (NCHRP 524):
  - Reduce delays when traffic volumes are high
  - Provide higher merging speeds
  - Useful when acceleration lane is long enough to allow a safe merge
  - Reduce accidents
- Median acceleration lanes are most effective at high-speed T-intersections on rural roads (NCHRP 524).
- Median acceleration lanes can help drivers complete a U-turn maneuver by allowing time to accelerate and merge with through traffic (NCHRP 524). This assumes that the median is of sufficient width to accommodate the U-turn maneuver.

Potential Difficulties

- Motorists must turn their head all the way around to look for safe gaps to merge into traffic. This can be especially difficult for older drivers.
- Kansas Department of Transportation Staff identified that some of their older facilities have median acceleration lanes but found that people don't tend to use them.
- There is little guidance available for the best geometric design for median acceleration lanes (NCHRP 500, V23). The design needs to balance the length to ensure that it is long enough to allow for safe merging maneuvers, yet not too long to be mistaken for an additional general purpose lane.
  - If a median acceleration lane is excessively long or poorly marked, through drivers may mistake it for an additional through lane (NCHRP 500).
  - The median acceleration lane needs to be long enough to allow for the safe merging of vehicles.
- The addition of median acceleration lanes may increase the width of the divided highway causing a potential problem for pedestrians attempting to cross the intersection. This problem may be solved by the installation of pedestrian refuge islands (NCHRP 500).
- A 1982 ITE survey resulted in the following disadvantages of median acceleration lanes (NCHRP 524, 19-20):
  - Difficult to merge because of blind spots
  - Not used properly by drivers
  - Create anxiety to through traffic
  - Create conflicts
  - Unexpected and unfamiliar to drivers
  - Benefits do not warrant construction costs

Compatibility with State and National Design Standards

- The Florida Department of Transportation Design Standards does not provide any guidance on the design and placement of median acceleration lanes within the state. For guidance on general median design, refer to AASHTO's *A Policy on Geometric Design of Highways and Streets,* 2004.

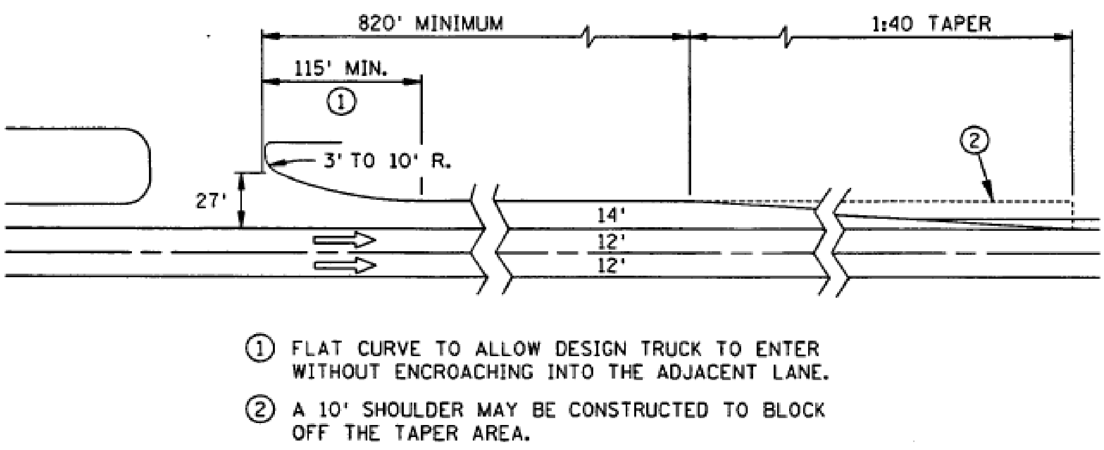
Design Considerations

- "Acceleration lanes should be of sufficient length to permit adjustments in speeds of both through and entering vehicles so that the driver of the entering vehicle can position the vehicle opposite a gap in the through-traffic stream and maneuver into that gap before reaching the end of the acceleration lane (NCHRP 500)."

- Implementation time may vary widely. NCHRP Report 500 identified projects that ranged in duration from 3 months to 4 years.
- In some cases, simple restriping could be enough to implement median acceleration lanes. Other times, road widening, cutting into the median, or acquiring additional right-of-way may be necessary (NCHRP 500).
- Costs may vary significantly depending on the existing site conditions and implementation plan (NCHRP 500).
    - Typically do not require purchase of any new right-of-way (Hanson).
    - "Based on past costs for this treatment, the cost for a 12-foot wide, 1500 feet in length lane was estimated at $115,000 (Hanson)." This assumes that sufficient median width is available and the mainline roadway does not require reconstruction.
- Signage at intersections with median acceleration lanes can greatly increase their effectiveness (Hanson, 2002).
    - "Signs such as 'Left-turning Traffic Use Acceleration Lane' or a diagrammatic sign could be installed to encourage drivers to use the median acceleration lane."
- For guidance on general median design, refer to AASHTO's *A Policy on Geometric Design of Highways and Streets*, 2004.
- The Minnesota DOT had constructed 10 median acceleration lanes as of 2002. Recommended lengths of the median acceleration lanes are provided below. This information is based upon the Minnesota DOT Road Design Manual, June 2004.

Recommended Lengths of MALs (Mn/DOT Road Design Manual)

Posted Speed (mph)	60% of Posted Speed (mph)	Desirable Length of Full Width MAL (ft.)
45	27	820
50	30	990
55	33	1195
60	36	1425
65	39	1670



Source: Minnesota DOT Road Design Manual, June 2004.

Treatment: Median Acceleration Lanes (Continued…)

- The Florida Greenbook does not specifically address median acceleration lanes; however, it does provide general information on acceleration lane lengths and taper lengths.

Table 13 Design Lengths for Speed Change Lanes – Grades 2% or Less (FDOT Greenbook, 2007)

Design Speed of turning roadway curve (MPH)		Stop Condition	15	20	25	30	35	40	45	50
Minimum curve radius (FEET)		---	55	100	160	230	320	430	555	695
Design Speed of Highway (MPH)	Length of Taper (FEET)*	Total length of ACCELERATION LANE, including taper (FEET)								
30	120	300	260	---	---	---	---	---	---	---
35	140	420	360	300	---	---	---	---	---	---
40	160	520	460	430	370	280	---	---	---	---
45	180	740	670	620	560	460	340	---	---	---
50	210	930	870	820	760	660	560	340	---	---
55	230	1190	1130	1040	1010	900	780	550	380	---
60	250	1450	1390	1350	1270	1160	1050	800	670	430
65	260	1670	1610	1570	1480	1380	1260	1030	860	630
70	280	1900	1840	1800	1700	1630	1510	1280	1100	860

Additional Reference Documents:

- Potts, I., D. Harwood, D. Torbic, K. Richard, J. Gluck, H. Levinson, P. Garvey, and R Ghebrial. *NCHRP Report 524: Safety of U-turns at Unsignalized Median Openings*. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2004).
- Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, E. Kohlman Rabbani. NCHRP *Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C. (2003).
- Hanson, Chad. *Median Acceleration Lane Study Report.* Minnesota Department of Transportation, District 6 Traffic Office (2002).
- American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets, 2003 Edition*. AASHTO: Washington, D.C. (2004).
- Minnesota Department of Transportation. *Road Design Manual (English)*. St. Paul, MN (2004).
- Florida Department of Transportation. *Florida Manual of Uniform Minimum Standards For Design, Construction, and Maintenance For Streets and Highways (Florida Greenbook).* Topic # 625-000-015. State Roadway Design Office, Tallahassee, FL (2007).

Description

Indirect left-turn treatments eliminate left turns at intersections by replacing them with vehicles making a right-turn followed by a U-turn in order to complete a left-turn maneuver. This treatment has been shown to be effective in reducing intersection crashes. Additional pavement is sometimes provided on the shoulder area to help facilitate left-turns, especially for heavy vehicles. This additional pavement area is sometimes referred to as the "Michigan Loon" and has been applied in Florida on parts of US 27 as shown in the photographs below. Additional elements could be incorporated into the design such as offset left-turn lanes to help improve visibility of approaching vehicles.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Some data available, crash reductions known but not certain
- **Estimated Effectiveness of the Treatment:** High
- **Crash Types Addressed:** Left-turn
- **Cost:** Medium to High
- **Time To Implement:** Medium to High

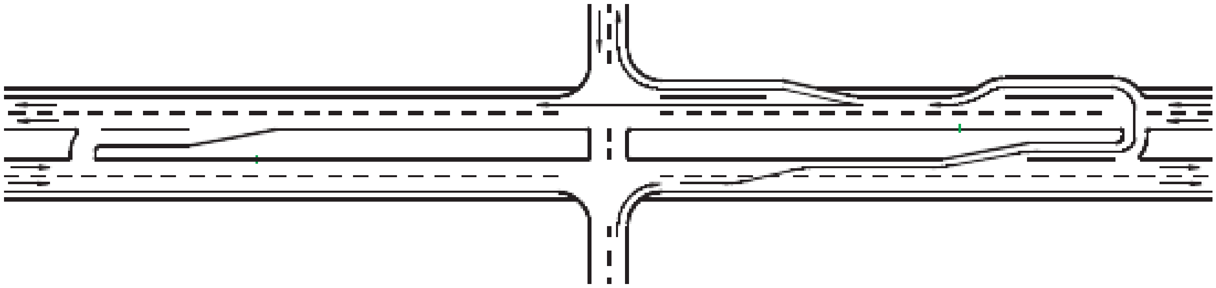


Figure 27 Typical Loon Design at a Directional Median Opening (NCHRP 524)

Source: Google Earth

Figure 28 U-Turn (Bulb-Out) Median Treatment (US 27, near Ocala, FL)

Applicability

This treatment is applicable at unsignalized intersections and may be incorporated into a broader access management planning effort for a corridor. Specific applications include locations where left-turns are difficult to make from the minor street due to volumes or sight restrictions, a very wide road or median, heavy traffic on the major street, and other complications. The use of indirect left-turns can minimize the effects of these operational and safety problems.

Potential Safety Benefits

- A 20-percent reduction in accident rate is estimated by *NCHRP Report 420* when direct left turns from driveways are replaced with right-turn/U-turn treatments (NCHRP 524). The table below shows the results from three unsignalized locations that were replaced by indirect left-turns:

STUDY RESULTS ON SAFETY EFFECTS OF INDIRECT LEFT-TURN TREATMENTS

Study by: Florida Department of Transportation
Year: 2004
Results:

- Over 250 sites evaluated
- On six-lane divided arterials with large traffic volumes, high speeds, and high driveway/side-street access volumes, the implementation of a right-turn/U-turn treatment leads to a statistically significant reduction in total crash rate of 26.4% as compared with direct left turns.
- The injury/fatality crash rate for right-turn/U-turns is significantly less than for direct left turns- a 32% reduction.

Reference: *NCHRP Report 524, p. 24*

Table 14 Accident Rate Differences: U-Turns as Alternate to Direct Left Turns (NCHRP 524)

Location	Treatment	Difference in accident rate
US-1, Florida	Driveway left turns replaced by right-turn/U-turn	–22%
Michigan	Bi-directional crossover replaced by directional crossover	+14%
Michigan	TWLTL replaced by directional crossover	–50%

- A special type of indirect left-turn treatment is the Median U-Turn Intersection Treatment (MUTIT). This treatment prevents directional left-turns from the major roadway at the actual intersection and instead requires left-turning vehicles to travel past the intersection and make a U-turn movement (similar to the movement that would be made for the minor street right-turn followed by U-turn). The Federal Highway Administration released a synthesis of this treatment titled: *Synthesis of the Median U-Turn Intersection Treatment, Safety, and Operational Benefits* (MUTIT) (Jagannathan, 2007). The synthesis identified the following benefits:
    - Reduced delay and better progression for through traffic on the major arterial
    - Increased capacity at the main intersection
    - Fewer stops for through traffic, especially where there are STOP-controlled directional crossovers
    - Reduced risk to crossing pedestrians
    - Two-phase signal control allows shorter cycle lengths, thereby permitting more flexibility in traffic signal progression
    - Fewer and more separated conflict points:
    - Shown to reduce injury crashes by approximately 50%.

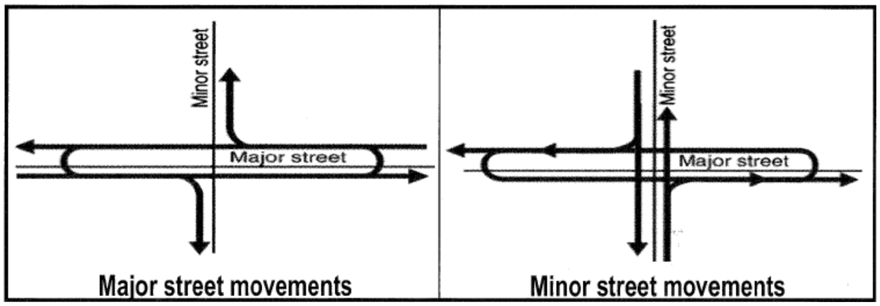


Figure 29 Vehicular movements at a MUTIT (Jagannathan, 2007)

Table 15 Conflict Points for Conventional Intersections and MUTIT (Jagannathan, 2007)

Conflict Type	Four-Leg Signalized Intersection	MUTIT
Merging/diverging	16	12
Crossing (left turn)	12	0
Crossing (angle)	4	4
Total	32	16

Table 16 Safety Comparison of MUTIT and Conventional Intersections (Jagannathan, 2007)

Dataset	Rate Type	Group	Mean Crash Rates (Crashes/MVE)	Standard Deviation	Alpha
Corridor	All	MUTIT (*Reduction*)	1.554 (*14%*)	0.784	73
		Conventional	1.806	0.679	
Intersection Related	All	MUTIT (*Reduction*)	1.388 (*16%*)	0.593	80
		Conventional	1.644	0.643	
	PDO	MUTIT (*Reduction*)	0.982 (*9%*)	0.392	49
		Conventional	1.077	0.467	
	Injury	MUTIT (*Reduction*)	0.407 (*30%*)	0.266	97
		Conventional	0.58	0.252	

Table 17 Expected Crashes for MUTITs and Conventional Intersections for a 5-year period (Jagannathan, 2007)

Crash Type	Injury Crashes				PDO Crashes				All Crashes			
	Conventional		MUTIT		Conventional		MUTIT		Conventional		MUTIT	
	%	Expected Crashes	%	Expected Crashes	%	Expected Crashes	%	Expected Crashes	%	Expected Crashes	%	Expected Crashes
Overturn	1.53	0.97	0.92	0.41	0.64	0.75	0.27	0.29	0.95	1.71	1.03	1.57
Fixed Object	3.56	2.26	4.25	1.89	4.77	5.62	6.97	7.5	4.36	7.85	6.13	9.38
Head-On	0.80	0.51	0.27	0.12	0.43	0.51	0.33	0.35	0.56	1.01	0.35	0.53
Angle St	36.87	23.4	19.77	8.8	18.35	21.63	9.06	9.75	24.73	44.53	12.12	18.54
Rear End	37.99	24.11	65.93	29.35	51.67	60.9	69.85	75.14	46.94	84.51	68.29	104.44
Angle Turn	3.56	2.26	4.76	2.12	6.71	7.91	7.74	8.33	5.62	10.12	6.84	10.46
Rear End Lt	1.53	0.97	0.81	0.36	4.18	4.93	0.93	1	3.27	5.89	0.88	1.35
Rear End Rt	0.20	0.13	0.65	0.29	1.45	1.71	1.43	1.54	1.02	1.84	1.19	1.82
Sdswipe Opp	0.20	0.13	0.13	0.06	0.27	0.32	0.22	0.24	0.25	0.45	0.20	0.3
Head-On Lt	13.75	8.73	2.52	1.12	10.89	12.84	2.75	2.96	11.87	21.37	2.66	4.07
Sdswipe same	0.00	0	0.00	0	0.64	0.75	0.44	0.47	0.42	0.76	0.31	0.47
Σ	100.00	63.47	100.00	44.52	100.00	117.87	100.00	107.57	100.00	180.04	100.00	152.93

Treatment: Indirect Left-Turn Treatments (Continued…)

Potential Difficulties

- The following disadvantages are identified in the FHWA *Synthesis of the Median U-turn Intersection Treatment, Safety, and Operational Benefits* ((Jagannathan, 2007)):
  - Possible driver confusion and disregard of left-turn prohibition at the main intersection
  - Possible increased delay, travel distances, and stops for left-turning traffic
  - Larger rights-of-way required for the arterial, although this potentially could be mitigated by the provision of loons on roads with narrow medians
- In urban areas, the use of U-turn cutouts or “loons” may be restricted by utilities, right-of-way, or other constraints.

Compatibility with State and National Design Standards

The Florida Department of Transportation Design Standards provides guidance on the design of directional median openings within the state. The information can be found in the FDOT Design Standards, Index 527.

Table 18 provides the FDOT access spacing standards. The standards show that the minimum spacing for directional median openings ranges from 1/8 to 1/4 mile. Both of these values are at the low end of what is being identified in other states as the preferred spacing for higher speed facilities.

Table 18 FDOT Access Spacing Standards

CONTROLLED ACCESS FACILITIES

ACCESS CLASS	FACILITY DESIGN FEATURES (MEDIAN TREATMENT AND ACCESS ROADS)	MINIMUM CONNECTION SPACING (FEET)	MINIMUM MEDIAN OPENING SPACING DIRECTIONAL (FEET)	MINIMUM MEDIAN OPENING SPACING FULL (MILE)	MINIMUM SIGNAL SPACING (MILE)
2	Restrictive with Service Roads	1320/660	1320'	0.5	0.5
3	Restrictive	660/440	1320'	0.5	0.5
4	Non-Restrictive	660/440	N/A	N/A	0.5
5	Restrictive	440/245	660'	0.5/0.25	0.5/0.25
6	Non-Restrictive	440/245	N/A	N/A	0.25
7	Both	125	330'	0.125	0.25

(Greater than 45 MPH/ Less than or = 45 MPH)

Source: FDOT Rule 14-97, Statewide Highway System Access Management Classification System and Standards, 11/27/1990.

Figure 30 shows the minimum median widths to accommodate U-turns based on the AASHTO *Green Book* Exhibit 9-92.

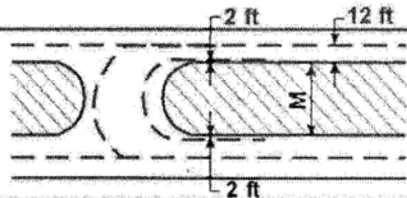
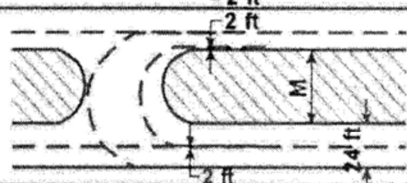
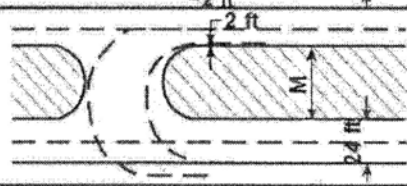
TYPE OF MANEUVER		M - MIN. WIDTH OF MEDIAN (ft) FOR DESIGN VEHICLE						
		P	WB-40	SU	BUS	WB-50	WB-60	TDT
		LENGTH OF DESIGN VEHICLE (ft)						
		19	50	30	40	55	65	118
INNER LANE TO INNER LANE		30	61	63	63	71	71	101
INNER LANE TO OUTER LANE		18	49	51	51	59	59	89
INNER LANE TO SHOULDER		8	39	41	41	49	49	79

Figure 30 AASHTO Minimum Median Widths to Accommodate U-turns (AASHTO)

Design Considerations

Considerations for the designs will be identified where applicable. Where significant design guidance is required, reference documents will be noted for further guidance to engineers.

- Where left-turns are restricted, the distance between the minor roadway and the location of the U-turn should be designed such that it minimizes out-of-direction travel yet provides enough distance to allow for safe weaving maneuvers.
    - Iowa DOT recommends a 1/3 to 1/2 mile distance, based upon survey feedback.
- Table 19 below shows the results of a study conducted for the FDOT by the University of South Florida in 2005 that identified minimum offset distances required between a driveway or minor-street and the downstream U-turn location.

Table 19 Minimum Offset Distances Between Driveways and Downstream U-turn

U-turn Location	Number of Lanes	Offset Distance (ft.)
Median Opening	4	400
	6 or more	500
Signalized Intersection	4	550
	6 or more	750

Note: Turn lane storage and transition lengths should be added to the minimum offset distance based upon the recommendations of the researcher.

Source: Lu, et al. *Determination of the Offset Distance between Driveway Exits and Downstream U-turn Locations for Vehicles making Right Turns Followed by U-turns. 2005.*

- Advance notification to drivers is important, both warning drivers before change is implemented and providing appropriate signage when change is in effect (NCHRP 500).
- Implementation time was can vary from 3 months to 4 years (NCHRP 500).
    - Less time if only appropriate signing is needed to implement
    - More time if major reconstruction of the roadway is needed
    - More time if additional right-of-way needs to be acquired
- Due to the drastically different implementation requirements for each specific project, the costs are highly variable as well. They range from nominal for simple signing and marking to over $100,000 per intersection approach for reconstruction (NCHRP 500).
- For information regarding the following topics and their relation to indirect left-turn treatments, see FHWA *Synthesis of the Median U-turn Intersection Treatment, Safety, and Operational Benefits* (Jagannathan, 2007):
    - Location and Design of Median Crossovers
    - Location and Design of Loons
    - Alternative Intersection Design
    - Capacity of Nonsignalized U-turn Lanes
    - Provision of a Signal Phase to Serve U-turns
    - Signal Phasing
    - Signing Plan
    - Traffic Operational Performance
    - Traffic Safety Performance
- For guidance on general median design, refer to AASHTO's *A Policy on Geometric Design of Highways and Streets*, 2004.

Additional Reference Documents:

- American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets, 2003 Edition*. AASHTO: Washington, D.C. (2004).
- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006).
- Florida Department of Transportation. Rules of the Department of Transportation, Chapter 14-97: State Highway System Access Management Classification System and Standards. http://www.dot.state.fl.us/planning/systems/sm/accman/pdfs/1497.pdf. Tallahassee, FL (1990).
- Jagannathan, Ramanujan. *TechBrief: "Synthesis of the Median U-turn Intersection Treatment, Safety, and Operational Benefits"*. Publication Number FHWA-HRT-07-033. Federal Highway Administration. Washington, D.C. (2007).
- Lu, J., P. Liu, F. Pirinccioglu. University of South Florida. Determination of the Offset Distance between Driveway Exits and Downstream U-turn Locations for Vehicles making Right Turns Followed by U-turns. Florida Department of Transportation, Tallahassee, FL (2005).
- Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, E. Kohlman Rabbani. NCHRP *Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C. (2003).
- Potts, I., D. Harwood, D. Torbic, K. Richard, J. Gluck, H. Levinson, P. Garvey, and R Ghebrial. *NCHRP Report 524: Safety of U-turns at Unsignalized Median Openings*. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2004).

Treatment: Offset Left-Turn Treatments

Description

Offset left-turn lanes involve specific striping and geometry of the intersection that allow vehicles to enter a left-turn-only lane and still see oncoming traffic without vehicles in the opposite left-turn lane obstructing their view. The turn lane is offset by about a few feet.

GENERAL TREATMENT INFORMATION

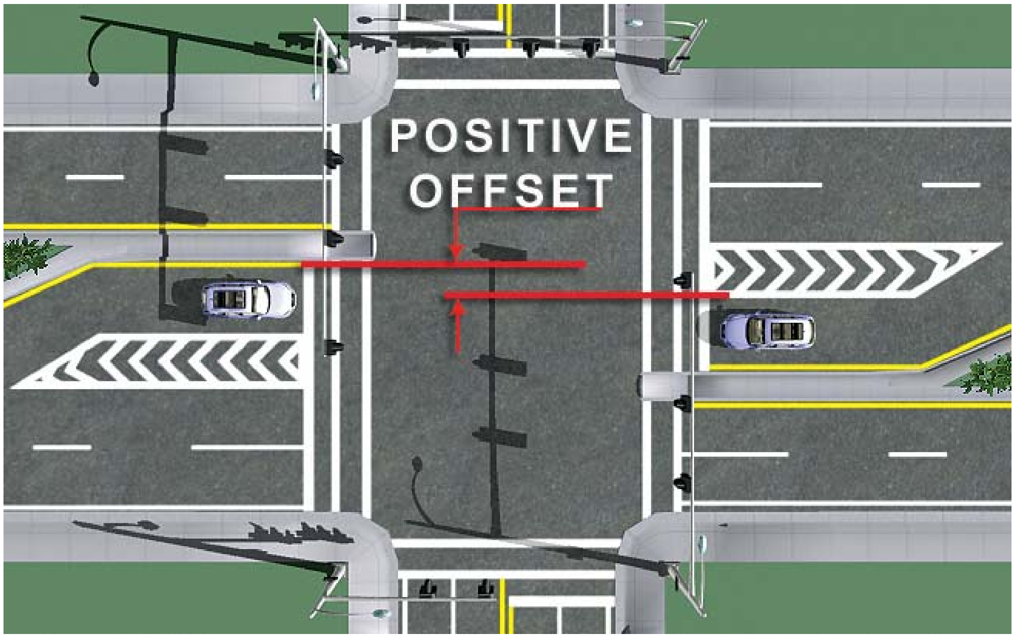
- **Treatment Level:** 2
- **Quantity of Known Research Data:** Some data available, crash reductions unknown
- **Estimated Effectiveness of the Treatment:** High
- **Crash Types Addressed:** Left-turn
- **Cost:** Medium to High
- **Time To Implement:** Medium to High

Applicability

Offset left-turn lanes may be an effective treatment in both a rural and urban environment to increase the sight-distance for the turning driver. The presence of an opposing left-turning vehicle can significantly limit the sight line for identifying conflicting vehicles within the opposing through lanes. This can be particularly problematic in urban areas where there is a much higher probability of an opposing left-turning vehicle being present. Offset left-turn treatments have been previously used in Florida, but are not a standard treatment. Direction in the use of offset left-turn lanes is currently provided in the FDOT Traffic Engineering Manual (TEM) with additional guidance provided in the FDOT Plans Preparation Manual (PPM).

Potential Safety Benefits

- Increase sight distance for turning driver so that conflicting vehicles can be identified
- Positive offset can be particularly helpful for older drivers who, according to the FHWA older driver handbook, tend not to optimize their position in the turn lane, and then have difficulty judging the speed of oncoming vehicles (Morena).



Source: 2001 Highway Design for Older Drivers and Pedestrians, FHWA.

Figure 31 Offset Left-Turn Lane

- Research has verified that offset left-turn lanes operate safely, but there are no reliable estimates of their safety effectiveness (NCHRP 500).
- Safety effectiveness is likely to depend upon the traffic volumes of the conflicting turning and through movements and the amount of offset between the left-turn lanes at the intersection (NCHRP 500).
- This strategy can be used easily in conjunction with other treatments to improve operational safety at unsignalized intersections (NCHRP 500).

Potential Difficulties

- Drivers may be initially confused by the change in traffic patterns, especially if offset turn lanes have not been used previously in that area (NCHRP 500).
- Offset turn lanes increase the width of the intersection which may cause a potential problem for pedestrians wishing to cross that intersection. Refuge islands in the median could be a potential solution for this problem (NCHRP 500).
- Offset left-turn lanes are a potential concern because they make U-turn maneuvers more difficult to complete because they move the starting point of the maneuver closer to the opposing roadway (NCHRP 524).

Compatibility with State and National Design Standards

The Florida DOT Plans Preparation Manual (January 1, 2007 Revisions) provides a discussion on the use of offset left-turn lanes in section 2.13.3.:

- On all urban designs, offset left-turn lanes should be used with median widths greater than 18 feet.
- In rural locations, offset left-turn lanes should be considered where there are high turning movements.
- A parallel offset turn lane design should be used where median widths are 30 feet of less and a tapered offset should be used where the median is wider than 30 feet.

The *Florida Median Handbook* discusses sight distance issues related to left-turn movements:

- A positive offset of 2 feet is recommended when the opposing left-turn vehicle is a passenger car.
- A positive offset of 4 feet is recommended when the opposing left-turn vehicle is a truck.

The Florida Department of Transportation Design Standards does not provide any guidance on the design and placement of offset left-turn lanes within the state.

Design Considerations

Considerations for the designs are identified below. Where significant design guidance is required, reference documents will be noted for further guidance to engineers.

- The strategy is generally applicable to intersections on divided highways with medians wide enough to provide the appropriate offset (NCHRP 500, V-18).
- Offset left-turn lanes can be provided in either a parallel or tapered configuration. The choice of design will depend on the size of the median and available distance for storage and transition area. (NCHRP 524):

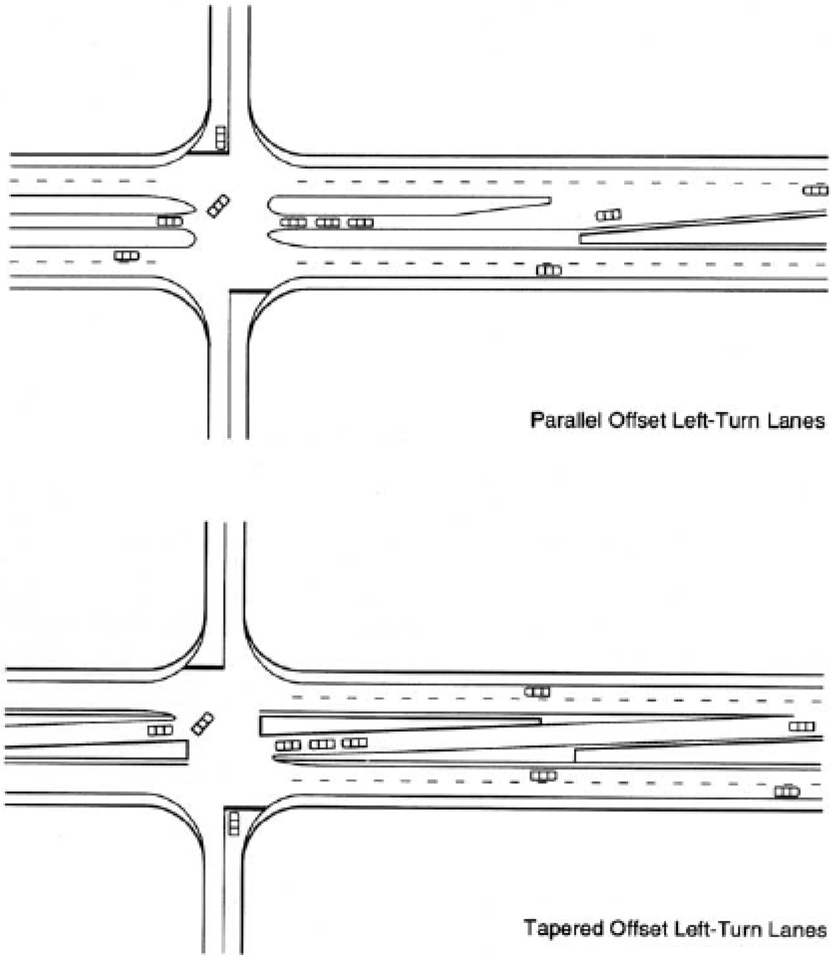


Figure 32 Offset Left-Turn Lane Design Options

- In some cases a wide median may require a larger offset to be effective.
- Even though the offset may not be enough to yield a positive offset, the negative offset may still significantly increase driver sight lines. See diagram below:

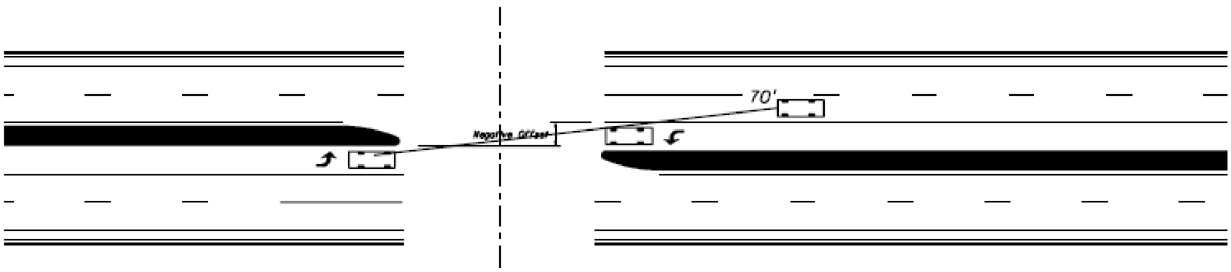


Figure 33 Typical Opposing Left-Turns (22' Median with negative 10' Offset)

Florida Department of Transportation. Plans Preparation Manual, Volume 1-English. January 1, 2006-January 1, 2007.

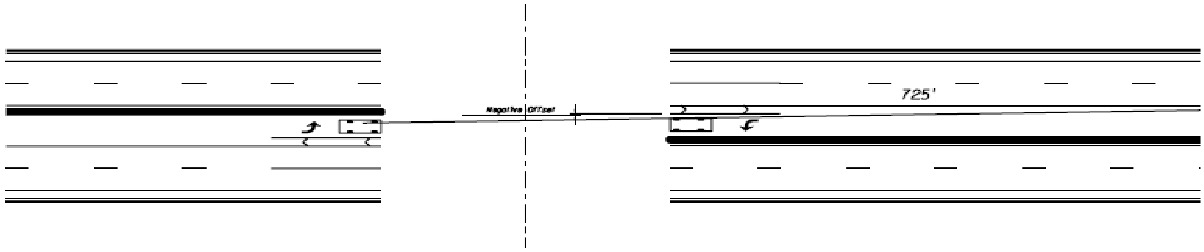


Figure 34 Typical Opposing Left-Turn (22' Median with Negative 1' Offset)

Florida Department of Transportation. Plans Preparation Manual, Volume 1-English. January 1, 2006-January 1, 2007.

- The timeframe for implementation ranges from 2 to 4 years depending on the geometry of the existing intersection (NCHRP 500).
- The relative cost to implement and operate is moderate to high compared to other safety improvements (NCHRP 500).
- The presence of heavy vehicles at a particular intersection may affect the amount of offset necessary to provide the desired effect.
- For guidance on general median design, refer to AASHTO's *A Policy on Geometric Design of Highways and Streets*, 2004.

Additional Reference Documents:

- Florida Department of Transportation. *Plans Preparation Manual*. Topic #625-00-007. Tallahassee, FL (2007).
- Neuman, T., R. Pfefer, K. Slack, D. Harwood, I. Potts, D. Torbic, E. Kohlman Rabbani. NCHRP *Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: -- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*. National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington D.C. (2003).
- Potts, I., D. Harwood, D. Torbic, K. Richard, J. Gluck, H. Levinson, P. Garvey, and R Ghebrial. *NCHRP Report 524: Safety of U-turns at Unsignalized Median Openings*. National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2004).
- Florida Department of Transportation. *Median Handbook, Interim Version*. Systems Planning Office, Tallahassee, FL (2006).
- Morena, David A.; Wainwright, W. Scott; Ranck, Fred. *Older Drivers at a Crossroads*. Public Roads. Federal Highway Administration, US Department of Transportation. January/February 2007, Vol. 70, No. 4. (July 2007). http://www.tfhrc.gov/pubrds/07jan/02.htm.
- American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets, 2003 Edition*. AASHTO: Washington, D.C. (2004).

Treatment: Roundabouts

Description

Roundabouts are a form of intersection control that have been implemented increasingly over the past since the late 1990's. The Florida Department of Transportation release the Florida Roundabout Guide in 1998, which was one of the first of such documents released in the U.S. to aid practitioners in roundabout design. Since their initial installation, roundabouts have been shown to improve safety, both with respect to overall crash rates and particularly with reducing injury crash rates. Crash reductions have been shown in a wide range of settings

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 3
- **Quantity of Known Research Data:** High
- **Estimated Effectiveness of the Treatment:** High, Known reductions to overall crashes and serious injury crashes
- **Crash Types Addressed:** Angle, Left-Turn, Speed Related
- **Cost:** High
- **Time To Implement:** High

Benefits include:

- Lower operating speeds result in fewer serious injuries and fatalities
- Reduces the number of intersection conflict points
- Facilities access management strategies by accommodating U-turns. This allows for corridor wide safety improvements.

Applicability

Roundabout could be utilized in a number of different settings including both urban and rural applications to improve safety, particularly with respect to reductions in injuries. Safety problems that may be corrected by a roundabout include:

- High rates of crashes involving conflicts right-angle, head-on, left/through, or U-turn crashes.
- High crash severity that could be reduced by slower speeds associated with roundabouts.
- Site visibility problems that reduce the effectiveness of stop signs control.

Potential Safety Benefits

STUDY RESULTS ON SAFETY EFFECTS OF MULTI-LANE ROUNDABOUTS

Intersection Type before Conversion to Roundabout (sample size)	% Reduction in All Crashes	% Reduction in Injury Crashes
All sites (55)	35	76
Signalized (9)	48	78
Two-way stop (36)	44	82
All-way stop (10)	No significant change	No significant change

Urban/suburban sites converted from TWSC (Sample Size)	% Reduction in All Crashes	% Reduction in Injury Crashes
All (27)	31	74
Single-lane (16)	56	78
Double-lane (11)	18	72

Source: NCHRP Report 572 *Roundabouts in the United States.* (2007)

- Roundabouts provide a particular benefit in reducing the rate/number of injury and fatal collisions. Recent findings of NCHRP Report 572 show a reduction of injury crashes of approximately 72% for multi-lane roundabouts. No fatal collisions were recorded for any of the roundabouts studied.
- Reductions in overall crashes were also found in NCHRP Report 572. Single lane roundabouts were found to have a higher reduction in overall crashes. The multi-lane roundabouts had a slightly lower improvement in overall crashes, but still yielded an overall reduction of approximately 18% for urban and suburban settings.
- Roundabouts can be used in conjunction with access management schemes to facilitate U-turn movements. Figure 35 provides an example of a similar treatment on a four lane arterial roadway in Colorado.
- In some cases, providing a roundabout at an intersection may eliminate the need for additional turning lanes. This helps to minimize the number of lanes along a roadway which may improve safety by minimizing lane changes.
- At locations with small minor street volumes relative to the major roadway, minor street drivers may experience high delays which results in their acceptance of smaller gaps. Accepting too small of a gap could result in a potential crash. A roundabout could help to improve the safety by requiring slower, more consistent speeds for all vehicles entering the intersection. Where significant imbalances exist between major and minor street volumes, a roundabout may introduce additional delay to the major road vehicles. When considering a roundabout at such a location, a roundabout the evaluation should carefully weigh the safety benefits against the operational analysis in determining the appropriate treatment.

Potential Difficulties

- The size of the multi-lane roundabout may be larger than the comparable signalized intersection – especially in the corners of the intersection. This may result in additional right-of-way at the intersection for a roundabout of sufficient size to both control vehicle speeds and accommodate the design vehicle.

- In rural locations (and along many state roadways within urban or suburban areas) the posted speed is often high. Roundabouts have been implemented on high speed facilities, including multi-lane roundabouts on roadways with posted speeds greater than 45 mph. Additional care should be taken on higher speed facilities to warn drivers of the upcoming intersection and ensure that the roundabout will provide appropriate speed control without.
- The signing and marking of multi-lane roundabouts should be carefully considered to provide appropriate lane configurations and appropriate lane utilization signing and markings to drivers. To ensure adequate performance from both a safety and operational perspective, the markings should reflect the operational analysis conducted for the intersection.
- On roadways with large cross-sections, 6 lanes or larger, care should be taken in planning and design.
    - A small number of three-lane roundabout have been constructed in the U.S., including a series of such roundabouts on a corridor in Colorado. A three lane roundabout may be considered where needed for capacity along a four lane roadway or to provide lane continuity along a six lane roadway. However, a careful review should be conducted from both an operations and design perspective.
    - Four lane roundabouts should not be considered at the current time.
- Careful analysis should be conducted for roundabouts proposed within coordinated signal systems. Although a roundabout may provide acceptable operations, the platooning of vehicles from upstream signals may affect the roundabout operations and vice-versa.

Figure 35 Arterial Multi-Lane Roundabouts Used For Access Management (Golden, Colorado)

Compatibility with State and National Design Standards

- Multi-lane roundabouts are becoming increasingly common throughout the United States, including Florida. Several existing multi-lane roundabouts are in operation in Florida, with many of the roundabouts located in urban or suburban settings. Design guidance is provided at both the state and national level specifically for roundabouts.
    - The Federal Highway Administration's Roundabouts: An Informational Guide (2001) provides guidance on the planning, operations, and design of roundabouts.
    - An earlier document, The Florida Roundabout Guide (1996) provides information related to the estimation of capacity at a two-lane roundabout, but offers design guidance primarily related to single-lane roundabouts.
    - Supplemental guidance from other states including Maryland, Kansas, Wisconsin, New York, Pennsylvania, and others provide more recent guidance and tips for multi-lane roundabout design

- The research document NCHRP Report 572 (2007) provides the most comprehensive evaluation of roundabouts in the United States to date.
- With regard to signing and markings at roundabouts
    - General guidance is provided in the Florida Intersection Design Guide related to roundabout signing.
    - The Florida DOT Traffic Engineering Manual, Section 4.4, provides detailed guidance on markings for many different configurations of multi-lane roundabouts. These standards reflect national level guidance.
    - The Florida DOT standard index drawings provide general guidance on overall state standards in signing and markings.

Design Considerations

- Roundabouts shall be yield controlled, with traffic circulating in a counter-clockwise direction around a center island.
- The roundabout design should control vehicle speeds to within 25 mph entering the intersection. The physical features of the design including the roundabout size, alignment of approach legs, entry width, and entry radii may all have an effect on the possible speeds through the roundabout. Checks of the fastest path speeds should be conducted, per the guidance contained in FHWA's *Roundabouts: An Informational Guide* to ensure adequate speed control for the roundabout.
- The intersection should be designed to accommodate the appropriate design vehicle. The appropriate design vehicle should be selected based upon guidance from the FDOT Traffic Engineering Manual and other state/local resources. The inscribed circle diameter (outside diameter) of the roundabout and the width of the truck apron should be sized appropriately to allow for navigation of the roundabout by large vehicles. The entry and exit widths and radii may also be affected by the design vehicle.
- For multi-lane roundabouts, the entry design should give consideration to the natural vehicle paths to ensure the design adequately aligns vehicles in the roundabout to avoid vehicle path overlap. Vehicle path overlap can occur when the design does not adequately align vehicles at the entry and the natural path of the outside vehicle causes it to 'cut-off' the vehicle traveling in the inside lane. The concept of vehicle path overlap and appropriate natural vehicle path are illustrated in Figure 36 and Figure 37, respectively. A design method for minimizing vehicle path overlap is provided in Figure 38.

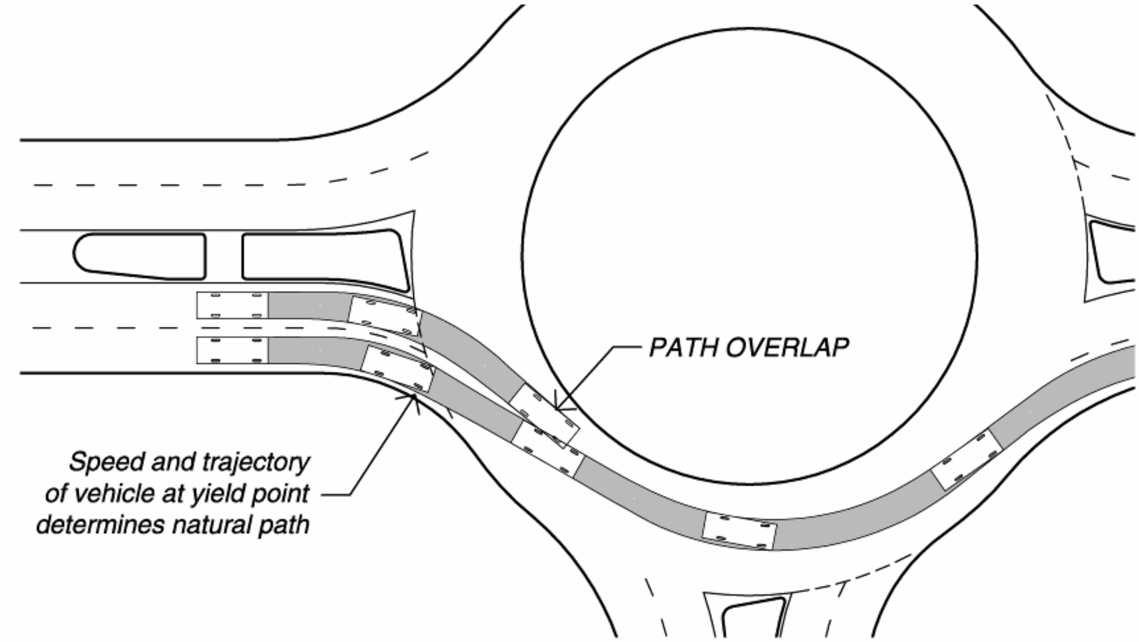


Figure 36 Vehicle Path Overlap

Source: Kansas Roundabout Guide, Exhibit 6-19, Pg. 81

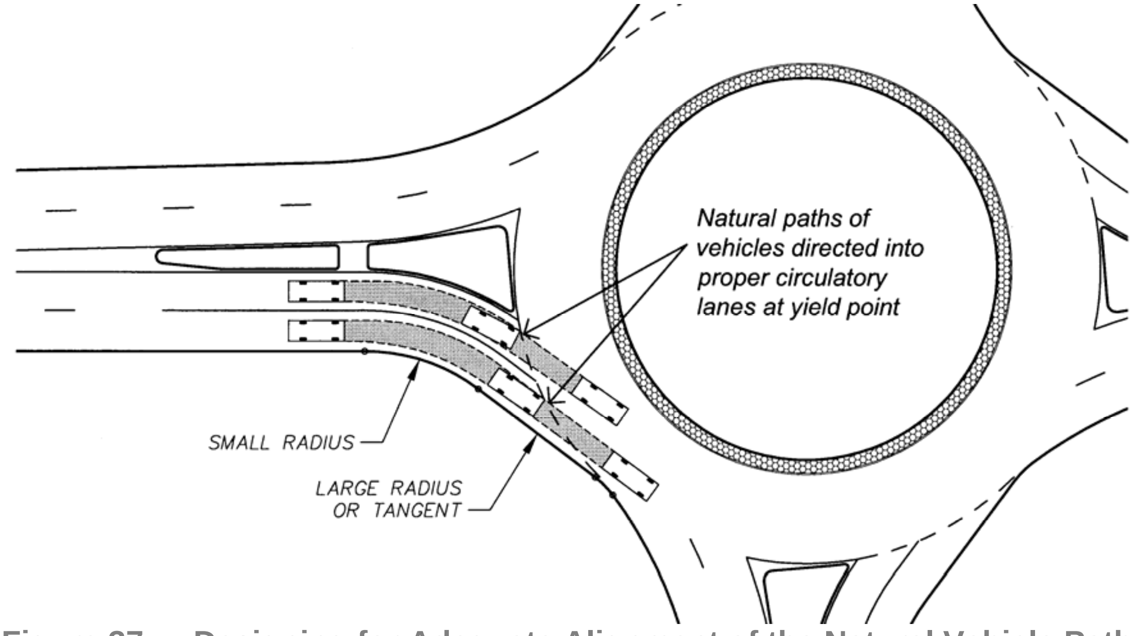


Figure 37 Designing for Adequate Alignment of the Natural Vehicle Paths

Source: Kansas Roundabout Guide, Exhibit 6-20, Page 82

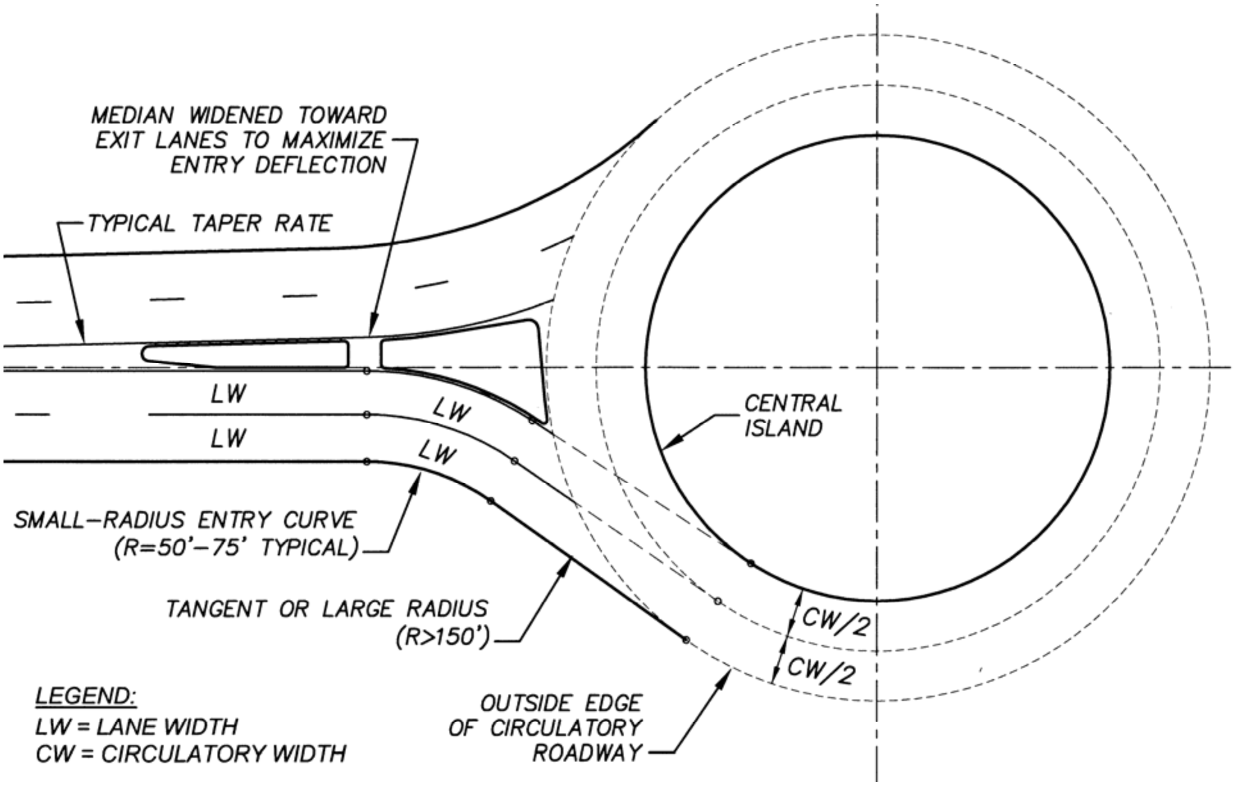


Figure 38 Design Considerations for Multi-Lane Entries

Source: Kansas Roundabout Guide, Exhibit 6-21, Pg. 83

Additional Reference Documents:

- Rodegerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter. *NCHRP Report 572: Roundabouts in the United States.* National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C. (2007).
- Federal Highway Administration. *Roundabouts: An Informational Guide*. Publication Number FHWA-RD-00-067. Washington, D.C. (2000).
- Florida Department of Transportation. *Florida Roundabout Guide.* Tallahassee, FL (1996).
- Florida Department of Transportation. *Traffic Engineering Manual*. FDOT Manual Number 750-000-005. Tallahassee, FL (1999).
  - Section 4.4 – Roundabout Markings
- Florida Department of Transportation. *Florida Intersection Design Guide*. Tallahassee, FL (2007).
  - Section 5.11 – Roundabout Signs and Markings
- Florida Department of Transportation. *Design Standards*, 2006 Edition, English Units. Topic No. 625-010-003. Tallahassee, Florida (2006).
  - Index 1736 – Special Marking Areas
  - Index 17355 – Special Sign Details
- Kansas Department of Transportation. *Kansas Roundabout Guide*. (2003).

Treatment: Minor Approach Splitter Islands

Description

Splitter islands are a raised or painted area on an intersection approach used to separate entering and exiting traffic, deflect and slow entering traffic, and provide refuge for pedestrians crossing the road in two stages (FHWA, Roundabouts An Informational Guide, 2000).

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 2
- **Quantity of Known Research Data:** Some data available, crash reductions uncertain
- **Estimated Effectiveness of the Treatment:** Medium
- **Crash Types Addressed:** Angle, Left-Turn
- **Cost:** Medium
- **Time To Implement:** Low to Medium

An example splitter island treatment is illustrated in Figure 39 at a rural roundabout. The extended splitter island helps to provide advance notice of the intersection to drivers. The raised nature of the splitter creates a change in the roadway cross-section which promotes speed reductions.

(Photo by Lee Rodegerdts)

Figure 39 Extended Splitter Island on Rural Roundabout Approach (Kansas)

Applicability

The concept of raised islands for other channelization is not new. Splitter islands are generally utilized at roundabouts, are often used to channelize right-turning vehicles, and are also often used on multi-lane roadways to separate traffic streams. However, raised splitter islands are less commonly used for smaller minor street roadways – which is the primary application being discussed within this section.

As part of FHWA's research on low-cost speed reduction treatments, a countermeasure is being considered that features channelizing islands on the minor street similar to the splitter islands that are used on roundabout approaches.

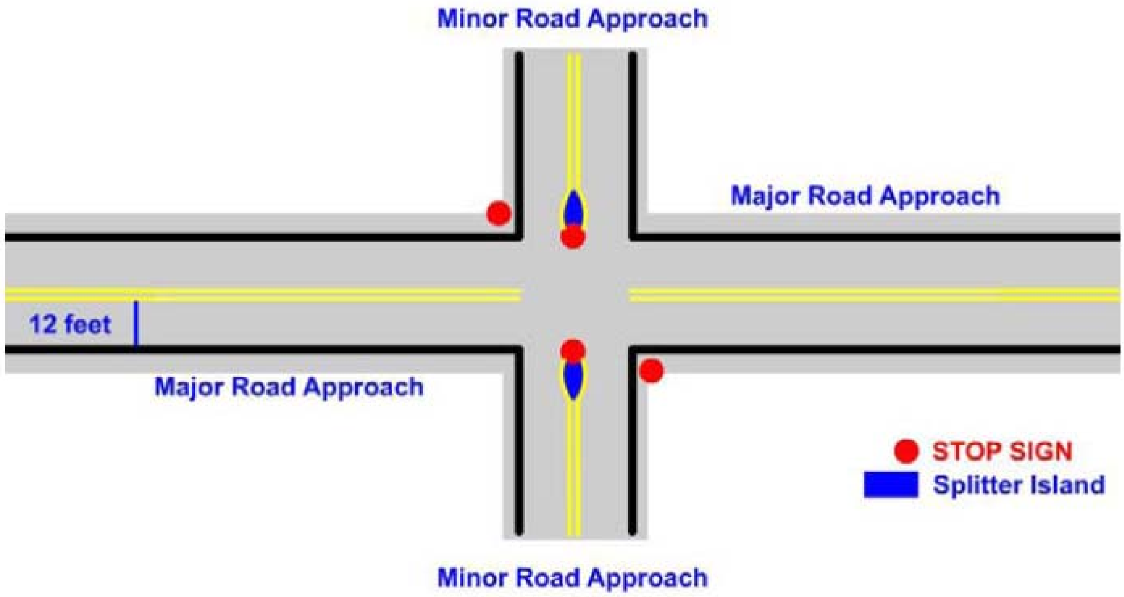


Figure 40 Splitter Island Treatment on Minor Road Approaches (FHWA Low-Cost Treatments)

Potential Safety Benefits

The goal of this treatment is to improve the visibility of the stop location to prevent drivers from running the stop sign or failing to yield to major road traffic. The treatment focuses on increasing intersection awareness and channelizing the traffic on the minor road approaches. The use of the splitter island median on the minor road also allows for two stop signs to be placed on each minor road approach to the intersection. Similar treatments in New Zealand and France resulted in a 30% reduction in total crashes and a 30% reduction in angle and crossing crashes (BMI-SG). One of the key features of these median islands in New Zealand and France was the creation of deflection at the intersection, which requires drivers to reduce their speed.

STUDY RESULTS ON SAFETY EFFECTS OF MINOR APPROACH SPLITTER ISLANDS

- Currently under investigation by FHWA.
- Studies in New Zealand and France indicated 30% reduction in total crashes and 30% reductions in angle and crossing accidents (BMI-SG)

Potential Difficulties

Some of the survey respondents expressed a concern with providing additional raised medians due to maintenance needs. Kansas DOT identified that the maintenance and replacement of raised curbing is a significant effort for their maintenance staff. They have also received requests from some local jurisdictions to remove raised medians at interchanges (in favor of simply using pavement markings) due to costs for curb replacement from truck off-tracking.

Design Considerations

The items below are general considerations for the design of splitter islands approaching an intersection.

- Design considerations for this type of treatment would include drainage considerations, truck turning paths, and the size of the median.

- Generally, raised medians
- The media should be large enough in size that it is conspicuous to the driver. A minimum surface area of 100 sq. ft. should be provided for the island (AASHTO, 2004)
- Islands should not be less than 4 feet wide. Where a pedestrian refuge will be provided within the splitter island, the island width should not be less than 6 feet to accommodate a bicycle or a person pushing a stroller.
- Islands should generally be a minimum of 20 to 25 feet in length for urban scenarios and 100 feet + in length for rural applications. (AASHTO, 2004)
- Where a pedestrian refuge is provided within the splitter island, ADA requirements must be met – including providing the refuge at the same surface as the adjacent roadway and the use of truncated dome detectable warning surfaces to define the edges of the refuge. See FDOT Standard Index drawing 304 for additional details.
- Appropriate offsetting and blunting of the approach noses to the splitter islands is recommended. Guidance is provided in both the AASHTO *Greenbook* and the FHWA document *Roundabouts: An Informational Guide* pertaining to design of splitter islands.
- For curb type information, refer to FDOT Standard Index drawing 300 for details.
- The implementation cost is tied to the size of the islands being proposed. Smaller islands, such as the 14 foot long islands proposed for the FHWA study, may cost as little as $4,000 - $5,000 per intersection site. For rural applications, longer splitter islands are recommended, which will increase the implementation costs.

As of the time this research was compiled, FHWA was sponsoring the testing of two splitter island treatments. Although tested for two-lane rural roadways, many of the same design details would be pertinent to providing splitter islands to the minor road approach of a multi-lane roadway. The drawings below illustrate the two concepts currently being tested.

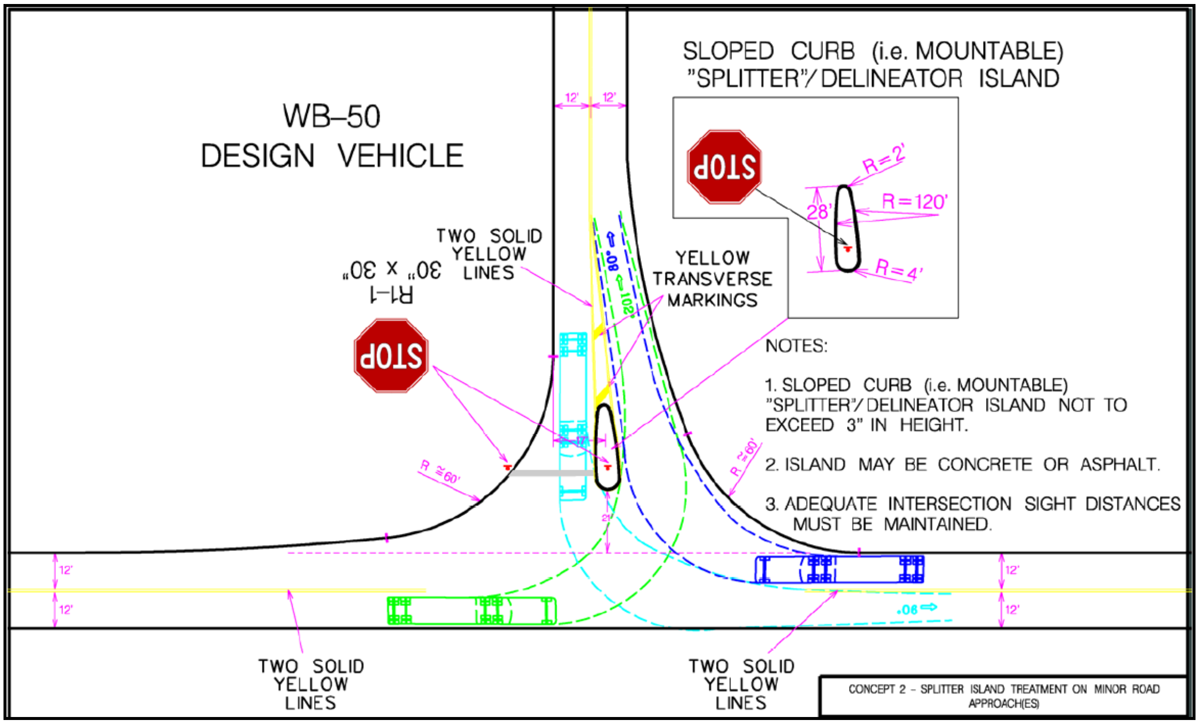


Figure 41 Splitter Island Treatment Option 1 - FHWA Low-Cost Speed Reductions Study

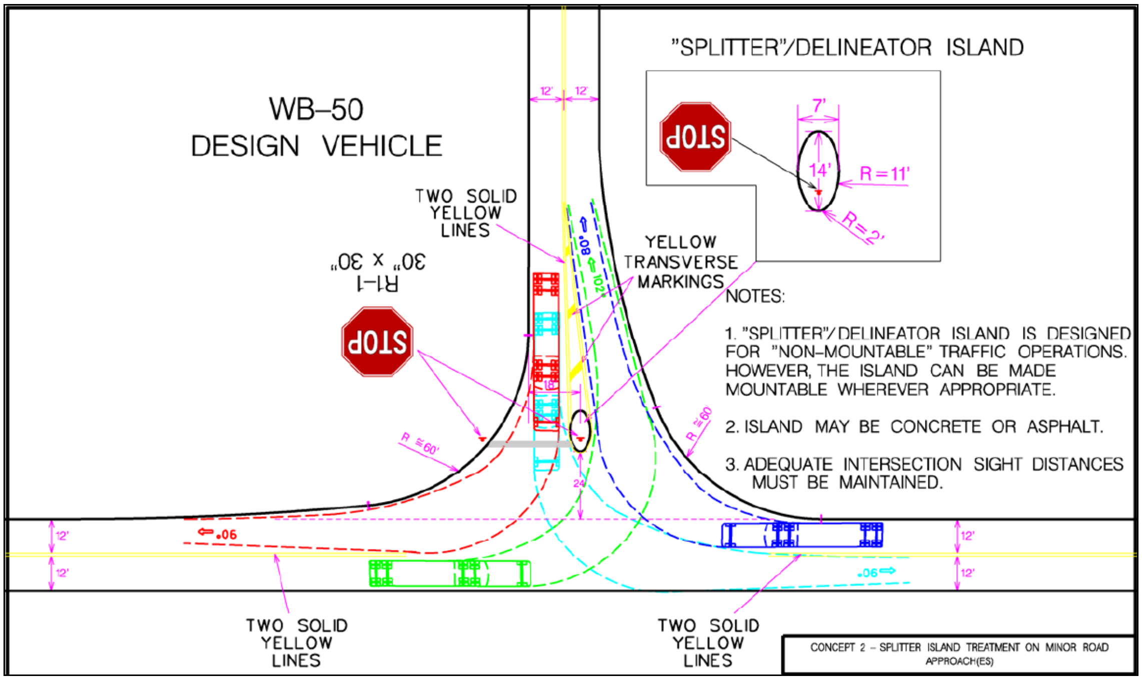


Figure 42 Splitter Island Treatment Option 2 - FHWA Low-Cost Speed Reductions Study

For both concepts being tested by FHWA, the drawings show truck turning paths for the two-lane major roadway. On multi-lane roadways with a median, right-turns from both the major and minor streets will be the critical turning movements. Larger turning radii will be available for trucks making left-turn maneuvers, which is expected to result in a lower likelihood for vehicles to hit the stop sign located within the minor roadway splitter island.

Additional Reference Documents:

- BMI-SG. Low Cost Speed Reduction Concepts research. Preliminary Work Plan for Task 3. Technical Support to the FHWA Office of Safety (2005).

- Federal Highway Administration. *Roundabouts: An Informational Guide*. Publication Number FHWA-RD-00-067. Washington, D.C. (2000).

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Treatment: Alignment Modifications/Reverse Curvature

Description

Reverse curvature is a treatment that is sometimes used on high speed approaches to roundabouts to force a speed reduction through the design of the geometric curvature. Application of this treatment to standard unsignalized intersections may help to better define the intersection location and reduce speeds of vehicles traveling through the intersection.

GENERAL TREATMENT INFORMATION

- **Treatment Level:** 3
- **Quantity of Known Research Data:** Little data available
- **Estimated Effectiveness of the Treatment:**Unknown
- **Crash Types Addressed:** Speed related
- **Cost:** High
- **Time To Implement:** High

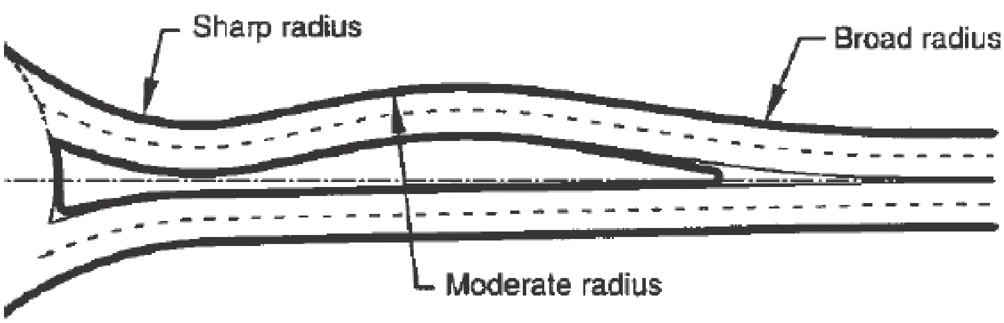

Figure 43 Approach Reverse Curvature (FHWA Roundabouts: An Informational Guide)

Applicability

The approach curvature consists of successive curves with progressively smaller radii. The curvature gradually reduces vehicle speeds so that all vehicles traveling through the intersection are operating at more consistent relative speeds. In roundabouts, slower speeds with a low speed differential between vehicles has been shown to result in reductions in both total and severe crashes.

On higher speed facilities with available right-of-way adjacent to the roadway, the re-alignment of the major street approaches may be an option for improving safety when other low cost treatment options have been exhausted.

Potential Safety Benefits

The use of reverse curvature on the approach to an unsignalized intersection could provide similar benefits as identified for roundabouts in controlling vehicle speeds. Through the gradual reduction of speeds approaching the roundabout, both the major and minor street drivers would be traveling at more similar speeds, thereby improving the minor street driver’s ability to estimate oncoming vehicle speeds and identify an acceptable gap. Slower speeds through the intersection may also result in a reduction in severe crashes.

Potential Difficulties

State DOT representatives and others survey participants indicated a reluctance to consider substantial geometric modifications (such as reverse curvature) approaching standard intersections on multi-lane roadways - even though it may provide speed reduction benefits. Generally, the survey participants indicated that they have used or would consider using reverse curvature on approaches to roundabout intersections.

The use of reverse curvature or other alignment modifications may not be feasible due to right-of-way, drainage, or other context specific considerations. The reduced speeds of vehicles on the minor roadway could be considered an unexpected event. Special attention should be given to the design of this type of countermeasure to prevent the treatment from being its own safety problem.

Design Considerations

- Design considerations include sight distance, roadway horizontal and vertical geometry, roadway speeds, right-of-way requirements and maintenance needs.
- Reverse curvature should be provided through successive curves with increasingly smaller radii (see Figure 43).
- Adequate horizontal curve lengths need to be provided to discourage drivers from off-tracking into adjacent lanes; however excessive curve lengths may not provide adequate speed reductions and could result in single vehicle crashes (NCHRP Project 3-74).
- Approach reverse curvature is not recommended for intersection approaches on downhill grades (NCHRP Project 3-74).
- A raised median should be provided to channelize and separate traffic flows. Refer to FDOT Standard Index 300 for details on curbing.

Additional Reference Documents:

- American Association of State Highway and Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets, 2003 Edition*. AASHTO: Washington, D.C. (2004).
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CONCLUSIONS AND SUGGESTED RESEARCH

This document has primarily focused on innovative treatments that may be considered to reduce crashes at unsignalized intersections on multi-lane, high speed roadways. It should be emphasized and as is illustrated in the case studies in Appendix A, the consideration of proven common treatments should be given the first priority after the contributing causes of the crashes have been identified. The best solution may be a combination of both common treatments and innovative treatments. Many of the innovative treatments presented in this document have not had extensive use thereby providing only limited information regarding the expected crash reduction. As innovative treatments are implemented, it is recommended that before and after studies be conducted to document the crash results and this information be shared. This will provide future users additional information in the evaluation of potential treatments to be considered at high crash, unsignalized intersections.

Some of the innovative treatments identified in this report are not approved for use either in the FDOT Approved Products List (APL) or the MUTCD. When this case arises, the user of this document should work with the FDOT District Traffic Operations Engineer and FDOT Traffic Operations in Central Office to obtain the necessary approvals for an experimental implementation of a treatment.

It is customary that the conclusion of a research report say “further research is needed”. In this particular case, the further research should be conducted when some of the identified innovative treatments have been implemented. It is important to gain further understanding regarding the potential level of success or failure a particular innovative treatment may provide.

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Appendix A

Case Studies

CASE STUDY 1 – SR 20 (ALACHUA COUNTY)
VEHICLE ACTUATE FLASHING BEACONS FOR 2-STAGE CROSSING

A section of State Road 20 in Alachua County was widened from a two-lane to a four-lane divided highway. The cross-section of the rebuilt roadway included a wide, 92-foot median. Within the 18-months of the roadway being widened, there were 12 crashes resulting in three fatal crashes at an intersection with a two-lane County Road 234. An investigation into the crashes resulted in a systematic approach to improving the intersection, initially with common treatments then with innovative treatments ultimately being utilized as the final set of improvements.

Intersection Data and Characteristics

The following is some key information pertaining to the intersection geometric and environmental characteristics.

- Newly Reconstructed Roadway – Built to FDOT standards, fresh markings and signing.
- Rural area with few scattered driveways and no substantial development along the highway.
- Perpendicular intersection angle.
- Only four-legged intersection within the divided roadway section. All others within the widened section are 'T' intersections.
- Sight distance well in excess of AASHTO and FDOT requirements.
- 4 lane roadway along SR 20, 2-lane roadway along County Road 234
    - Exclusive left-turn lanes provided along SR 20
- Wide median (92 feet in width) with a standard FDOT median opening (bullet-nose shape) with markings per FDOT Standard Index Number 17346.
- Posted speed on SR 20 is 65 mph and 45 mph on the County Road
- A school bus stops along SR 20 in the vicinity of the intersection.
- Rumble strips are located along the County Road approaching the intersection with SR 20 (these were present prior to the widening of SR 20).

Determination of Crash Cause

11 of the 12 crashes had nearly an identical pattern: Vehicles traveling on the County Road intending to travel straight through the intersection (across SR 20) would get hit by an opposing vehicle on the far side of the intersection. All vehicles were believed to have stopped appropriately at the stop sign, which indicated that visibility of the intersection and driver compliance were not sources of the crash problem. Observations of the intersection indicated that motorists were attempting to negotiate the entire crossing as one intersection, not realizing how wide the intersection really was and how fast the mainline SR 20 traffic was approaching. Therefore the root problem identified was that drivers were having difficulty judging vehicle oncoming vehicle speeds and adequately assessing acceptable gap sizes.

Selection of Countermeasures

A number of different treatments were considered, including closing the median opening and requiring drivers to make a right-turn followed by a U-turn. Local residents strongly opposed this idea, instead asking for a traffic signal. Isolated traffic signals on rural roadways have been found to have poor safety performances, leading to an increase in rear-end collisions without necessarily reducing the likelihood of an angle collision. Further, the volume warrants were not met at this location and therefore a traffic signal was not considered a viable improvement.

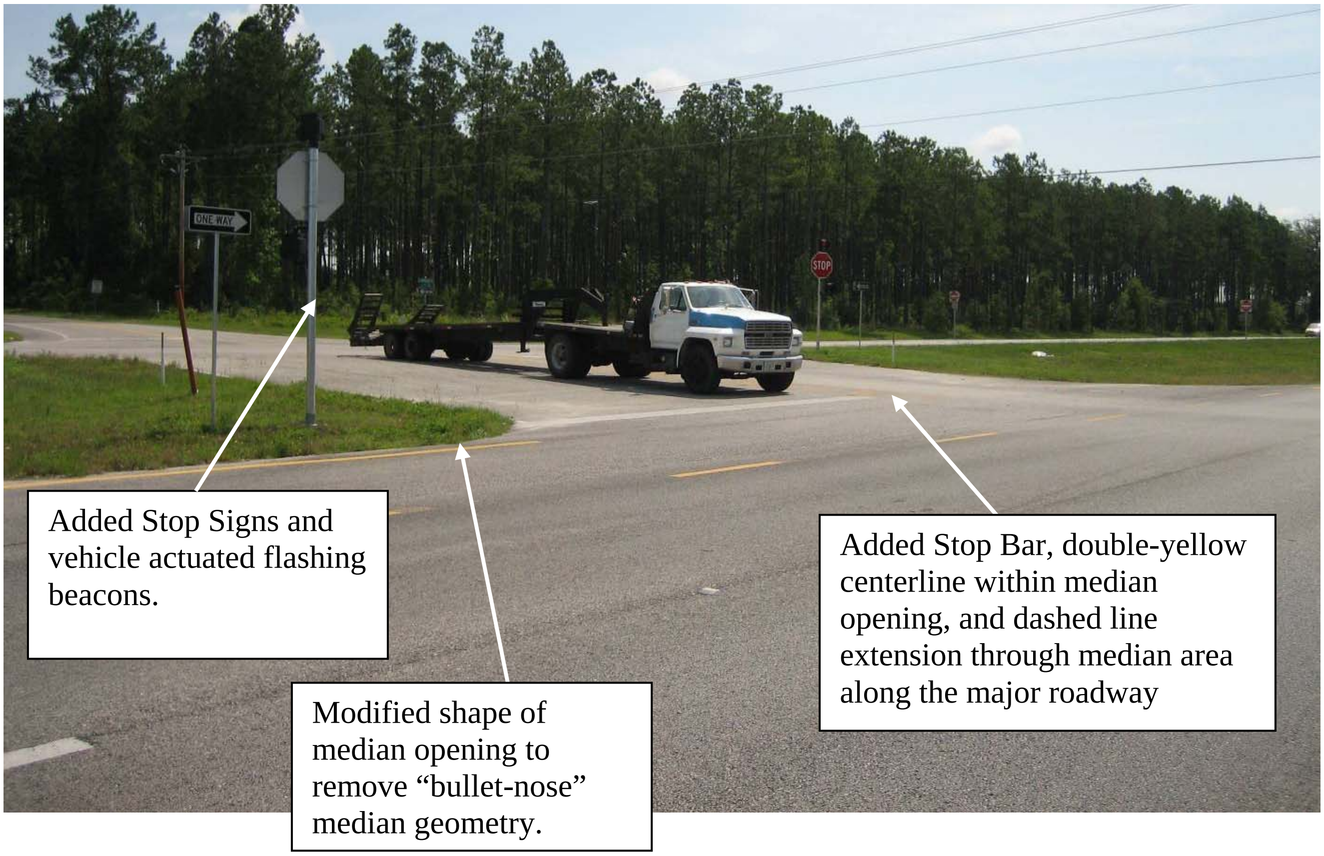
Initial Implementation

Due to the available median width, it was determined that negotiating the intersection in two steps (two-stage gap acceptance) would allow drivers to sufficiently judge speeds and gaps to make better judgments when crossing SR 20. To encourage motorists to stop in the median the following treatments were initially installed within the median: (1) stop signs and corresponding stop bar pavement markings and (2) double yellow centerline. The placement of stop signs and other markings within the median area is not a common practice in Florida, however the implementation used common signs and markings – which are familiar to drivers.

The initial implementation, although well thought out, did not appear to resolve the problem. Motorists ignored the stop sign within the median and continued to attempt to navigate the intersection in one stage. One theory was that the shape of the median opening, with the ‘bullet-nose’ shape and significant length, made the median visually appear to be too narrow to store a vehicle within. Therefore drivers were hesitant to stop within the median. The shape of the median also meant that the stop sign within the median was located outside the driver’s field of vision as they were entering the intersection.

Follow-Up Treatments

To supplement the initial treatments, a secondary plan was prepared to further encourage the two-stage gap acceptance at the intersection. A geometric improvement was constructed to reduce the size of the median and eliminate the ‘bullet-nose’ shape. The reconstructed median was made to resemble a short-cross street rather than a wide median opening.



A system was also constructed that implemented vehicle-actuated flashing beacons. Flashing red beacons were placed above and below the stops signs both at the initial stop location on the outside of SR

20 and within the median. The beacons at the initial stop location are programmed to constantly flash, while the beacons within the median are vehicle actuated. Therefore, as motorists approached the intersection along SR 20 the initial stop location is clearly visible due to the flashing beacons. Once the motorist stops at the stop sign, a loop detector at the stop bar activates the red flashers within the median. It also activates yellow flashers mounted on the post for the Intersection Ahead warning sign along SR 20. This set of activated flashers alerts motorists to the need to stop within the median, while also alerting SR 20 motorists to the presence of a conflicting vehicle. The cost for the reconstruction of the median and placement of the actuated beacons was approximately $60,000 ($90,000 with design costs included) in 2004 dollars.

This set of treatments was shown to reduce the number of crashes to six reported collisions, one injury, and zero fatalities in the two years following implementation. This innovative treatment relied primarily on off-the-shelf products such as loops, beacons, signs, and markings. However they were combined in a way that worked to resolve the specific safety issues identified at this location. Even though the initial set of treatments did not resolve the problem, it provides a good example of the steps that are required in the process: from identifying the problem to first applying the common treatments, to then implementing more innovative measures. It should also be noted that several different treatments were installed – both common and innovative – to resolve the identified safety problem.

CASE STUDY 2 – I-95 AT SR 84
VEHICLE ACTUATED IN-ROADWAY LIGHTING FOR SPEEDING

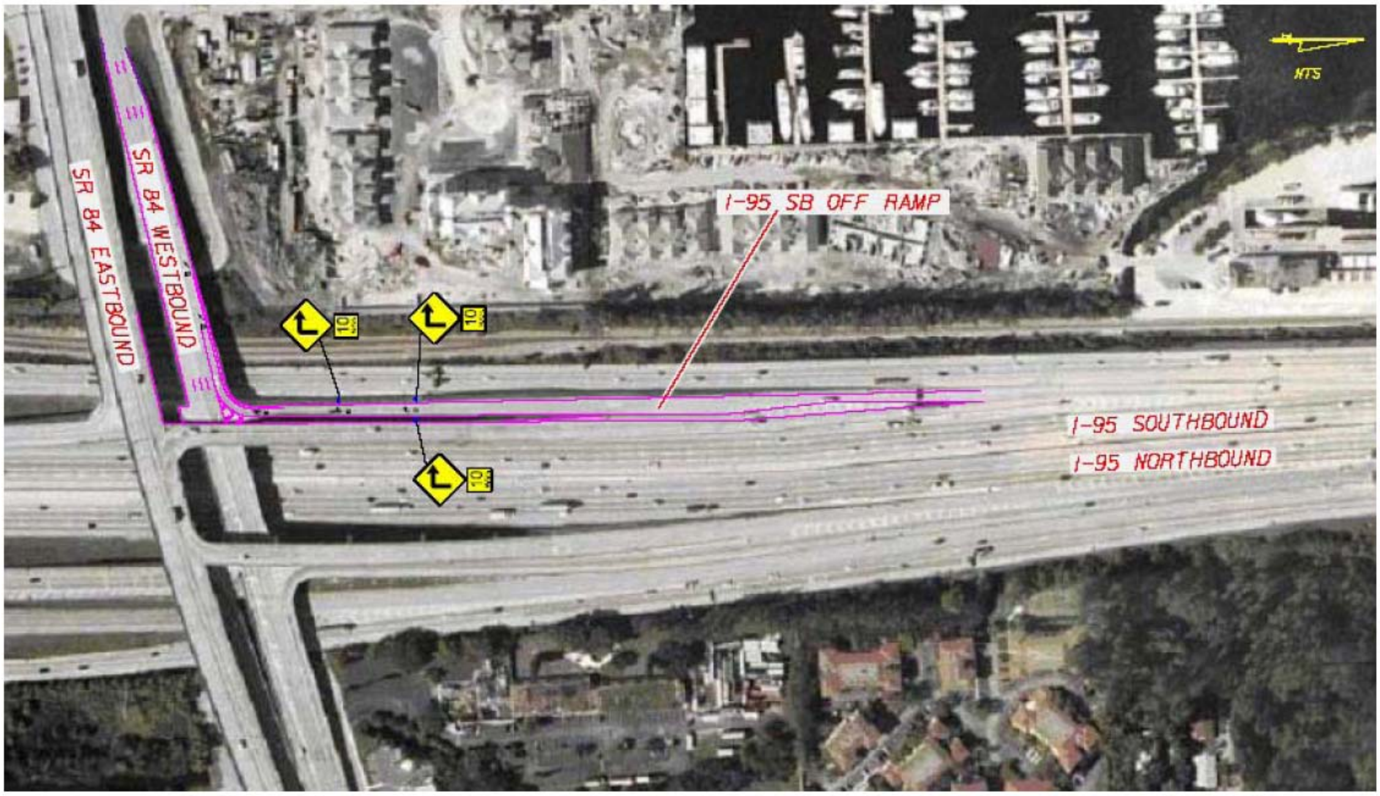
At the interchange of I-95 with State Road 84 in Fort Lauderdale, Florida, the southbound off-ramp from I-95 had a history of safety problems. The Interstate 95 off-ramp terminates into a sharp 10-mph free-flow curve that merges onto SR 84 Westbound. The high speeds of the exit ramp would catch motorists by surprise and result in out-of control crashes.

Intersection Data and Characteristics

The following is some key information pertaining to the intersection geometric and environmental characteristics.

- Single-lane off-ramp with an advisory speed of 10 mph.
- Ramp length approximately ½ mile long
- Ramp forms a T-intersection with SR 84 Westbound. SR 84 is a divided roadway with no left-turn access from the ramp. Ramp traffic is channelized onto SR 84 with a free-flow right turn lane.
- Two sets of warning signs upstream of the intersection indicate the 90-degree turn and provide a 10 mph advisory speed plaque.

The following three photos provide an illustration of the roadway conditions from an aerial perspective, from the intersection, and along the ramp from a drivers perspective.



Roadway Conditions Prior to Improvement (Gilbert Soles, FDOT District 4)

Roadway Conditions Prior to Improvement (Gilbert Soles, FDOT District 4)

I-95 Off-Ramp From Driver Perspective (Photo Source: Joseph Bansen)

Determination of Crash Cause

Speed studies conducted along the freeway off-ramp identified that drivers were traveling on the ramp at near-highway speeds. Speeds ranged from approximately 50 to 60 mph upstream of the 10 mph right-turn. The length of the ramp was considered to be one contributing factor, since it allowed drivers to continue at the highway speeds.

Day of the week	Time Period	85th Percentile Speed
Weekday (Thursday)	7:00 am - 8:00 am	60 MPH
	12:00 pm - 1:00 pm	57 MPH
	4:45 pm - 5:45 pm	53 MPH
	7:00 pm- 8:00 pm	51 MPH
Weekend (Saturday)	9:00 am - 10:00 am	56 MPH
	12:00 pm - 1:00 pm	55 MPH
	4:00 pm - 5:00 pm	55 MPH
	7:00 pm- 8:00 pm	54 MPH

Approximately 70% of the crashes were identified as angle or right-turn type crashes. Additionally, 77% of the crashes were attributed to speeding. The speeds of the vehicles result in out-of control crashes where motorists are not able to stay within the channelized right-turn lane – an in some instances traveling across the roadway and striking the roadway barrier on the far side of the intersection.

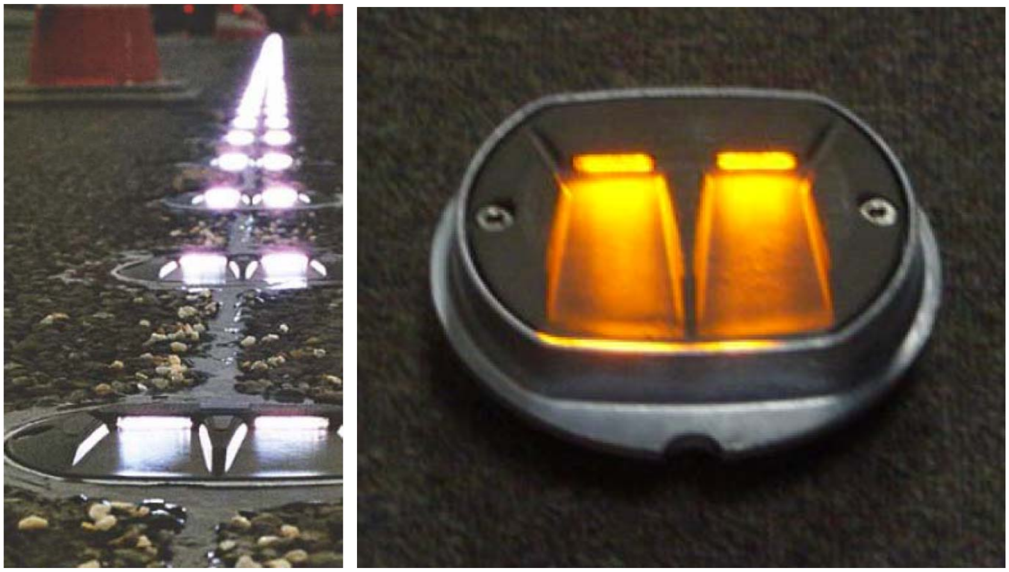
Selection of Countermeasures

FDOT District 4 selected an active installation of embedded LED lights at the interchange ramp of I-95 and SR 84 that was installed in late 2004. Pavement loop detectors measure drivers speed and activate the embedded LED lights when vehicle speeds exceed 45 mph (the ramp advisory speed is 10 mph). The lights operate in flash mode to alert drivers that they are driving too fast to negotiate the curve at the bottom of the exit ramp. Lights are embedded from the start of the ramp to end of the 90-degree free-flow right turn at the bottom of the ramp.

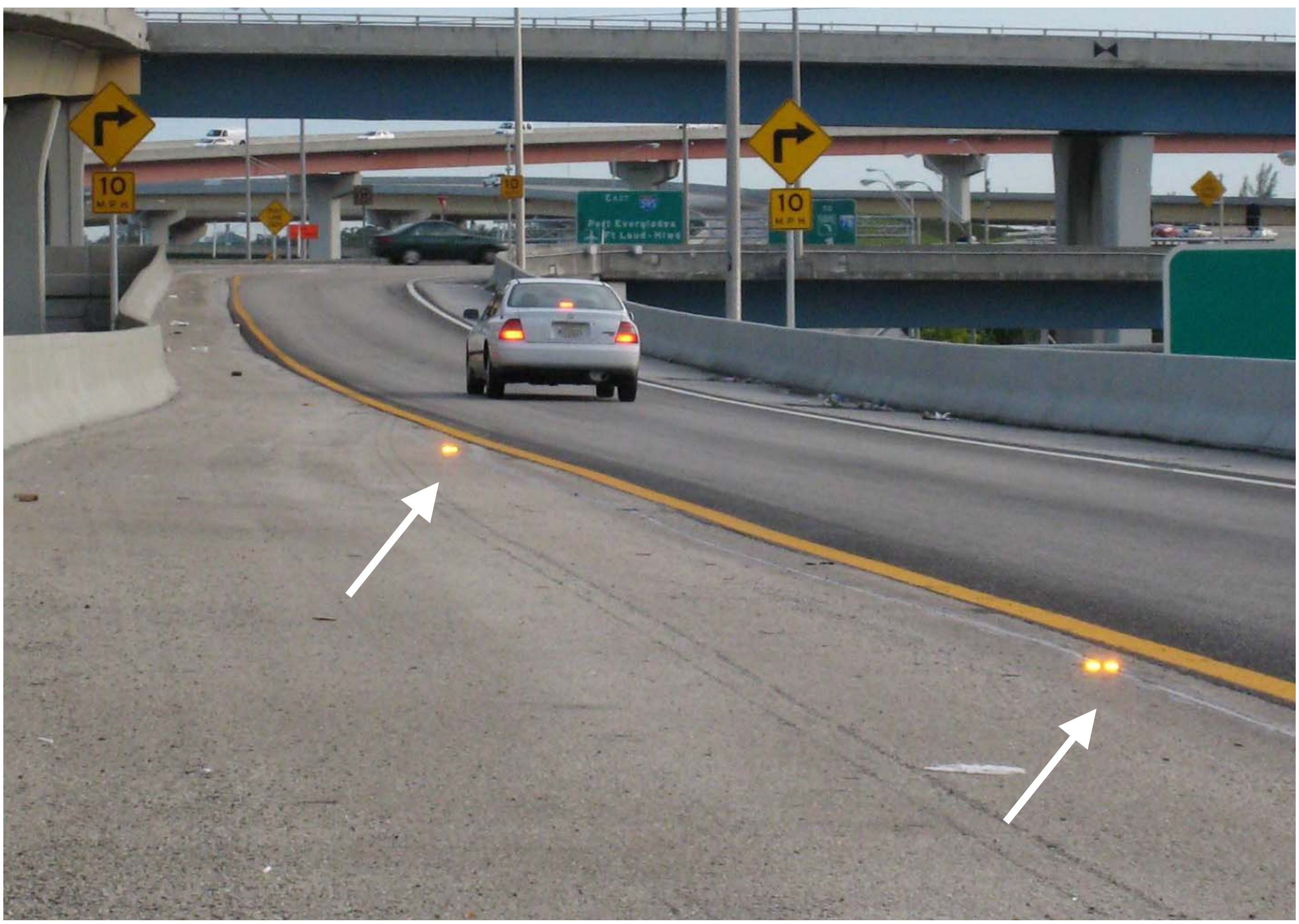
For in-roadway lights, the MUTCD currently only has provisions that allow installations at pedestrian crossings. Section 4L-1 provides the standards and guidance for installations of embedded, in-roadway lighting. Due to the existing limitations of the MUTCD, the FDOT project was installed with experimental permission from FHWA that includes requirements for monitoring and reporting its effectiveness.

Conclusion

Although this case study is not the typical example of an unsignalized intersection, it demonstrates a comprehensive approach to identifying the root issue associated with a crash problem and then developing an appropriate countermeasure. To resolve the crash problem, innovative treatments were considered, with approval gained from FHWA to install and test the countermeasure. Full results of the effectiveness of this treatment are expected to be available in 2008.



In-Pavement LED Lighting (Gilbert Soles, FDOT D4)



Vehicle Speed Actuated In-Pavement Lighting (Photo Source: Joseph Bansen)

Appendix B

Supplemental References

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